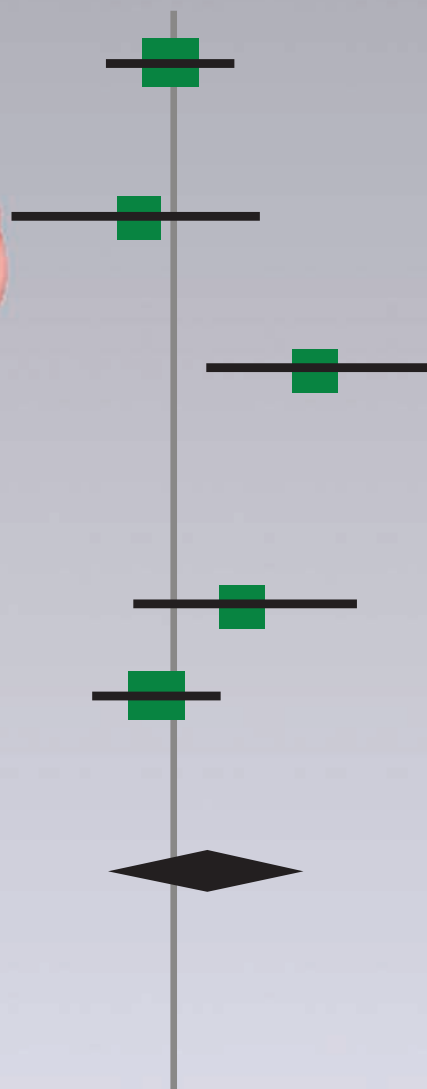


Evidence-Based Orthodontics

Greg J. Huang, Stephen Richmond & Katherine W.L. Vig



VISIT...

LANZAROTE
Caliente.COM

Evidence-Based Orthodontics

Evidence-Based Orthodontics

Edited by

Greg J. Huang, DMD, MSD, MPH

**Stephen Richmond, BDS, DOrth RCS, MScD,
FDSRCS, PhD, FHEA**

Katherine W.L. Vig, BDS, MS, DOrth RCS, FDSRCS

 **WILEY-BLACKWELL**

A John Wiley & Sons, Inc., Publication

This edition first published 2011 © 2011 by Blackwell Publishing, Ltd.

Blackwell Publishing was acquired by John Wiley & Sons in February 2007. Blackwell's publishing program has been merged with Wiley's global Scientific, Technical and Medical business to form Wiley-Blackwell.

Registered office: John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial offices: 2121 State Avenue, Ames, Iowa 50014-8300, USA
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
9600 Garsington Road, Oxford, OX4 2DQ, UK

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell.

Authorization to photocopy items for internal or personal use, or the internal or personal use of specific clients, is granted by Blackwell Publishing, provided that the base fee is paid directly to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923. For those organizations that have been granted a photocopy license by CCC, a separate system of payments has been arranged. The fee codes for users of the Transactional Reporting Service are ISBN-13: 978-0-8138-0614-3/2011.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Library of Congress Cataloging-in-Publication Data

Evidence-based orthodontics / edited by Greg J. Huang, Stephen Richmond, Katherine W.L. Vig.
p. ; cm.

Includes bibliographical references and index.

ISBN 978-0-8138-0614-3 (paperback : alk. paper) 1. Orthodontics. 2. Evidence-based dentistry. I. Huang, Greg J., editor. II. Richmond, Stephen, editor. III. Vig, Katherine W.L., editor. [DNLM: 1. Orthodontics. 2. Evidence-Based Dentistry. 3. Malocclusion—therapy. WU 440] RK521.E975 2011
617.6'43—dc22

2010048237

A catalogue record for this book is available from the British Library.

This book is published in the following electronic formats: ePDF [9780470959749]; ePub [9780470959756]

Set in 10 on 12 pt Times by Toppan Best-set Premedia Limited

Disclaimer

The publisher and the author make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation warranties of fitness for a particular purpose. No warranty may be created or extended by sales or promotional materials. The advice and strategies contained herein may not be suitable for every situation. This work is sold with the understanding that the publisher is not engaged in rendering legal, accounting, or other professional services. If professional assistance is required, the services of a competent professional person should be sought. Neither the publisher nor the author shall be liable for damages arising herefrom. The fact that an organization or Website is referred to in this work as a citation and/or a potential source of further information does not mean that the author or the publisher endorses the information the organization or Website may provide or recommendations it may make. Further, readers should be aware that Internet Websites listed in this work may have changed or disappeared between when this work was written and when it is read.

Table of Contents

Foreword	vii
<i>Gordon Guyatt</i>	
Contributor List	ix
Part 1 Principles	3
Chapter 1 A Historical Perspective of Evidence-Based Orthodontics	5
<i>Katherine W.L. Vig</i>	
Chapter 2 Clinical Research Designs	15
<i>Robert J. Weyant</i>	
Chapter 3 Electronic Searching for Clinical Trials Information	31
<i>Anne Littlewood</i>	
Part 2 Selected Topics	47
Chapter 4 The Treatment of Class II Malocclusion—Have We the Evidence to Make Decisions?	49
<i>Kevin O'Brien and Jonathan Sandler</i>	
Chapter 5 External Root Resorption and Orthodontic Treatment—Assessment of the Evidence	63
<i>Belinda J. Weltman</i>	
Chapter 6 Malocclusion, Orthodontic Treatment, and Periodontal Health—An Assessment of the Evidence	89
<i>Anne-Marie Bollen</i>	
Chapter 7 Stability of Anterior Open Bite Correction—An Assessment of the Evidence	97
<i>Greg J. Huang and Geoffrey M. Greenlee</i>	
Chapter 8 Orthodontics and Temporomandibular Joint (TMJ) Disorders	119
<i>Friederike Luther and Fraser McDonald</i>	
Chapter 9 Self-Ligation	135
<i>Padhraig S. Fleming</i>	

Chapter 10	Prevention of Demineralization During Orthodontic Treatment with Fluoride-Containing Materials or Casein Phosphopeptide-Amorphous Calcium Phosphate <i>Philip E. Benson</i>	149
Chapter 11	Invisalign Therapy—A Systematic Review of Lower Quality Evidence <i>Jason M. Bressler, Stefanie Hamamoto, Gregory J. King, and Anne-Marie Bollen</i>	167
Chapter 12	Retention <i>Simon J. Littlewood, Declan T. Millett, David R. Bearn, Bridget Doubleday, and Helen V. Worthington</i>	181
Chapter 13	Quality of Outcome <i>Stephen Richmond and Alexei Zhurov</i>	191
Chapter 14	Stability of Orthognathic Surgery <i>Donald R. Joondeph</i>	217
Chapter 15	Orthodontic Treatment of the Transverse Dimension—Assessment of the Evidence <i>Steven D. Marshall</i>	233
Chapter 16	Class III Malocclusion—The Evidence on Diagnosis and Treatment <i>Joseph G. Ghafari, Ramzi V. Haddad, and Maria E. Saadeh</i>	247
Part 3	Evidence-Based Orthodontics in Perspective	281
Chapter 17	Evidence-Based Care in Context <i>William Shaw</i>	283
Chapter 18	Playing Doctor: Evidence-Based Orthodontics <i>Lysle E. Johnston, Jr.</i>	293
Chapter 19	Reflections on a Decade of Evidence-Based Dentistry <i>David L. Turpin</i>	301
Index		307

Foreword

Evidence-based medicine (EBM)—or evidence-based surgery, or evidence-based orthodontics (EBO)—is about solving clinical problems. In particular, EBO provides tools for using the relevant literature to determine the benefits and risks of alternative patient management strategies and to weigh those benefits and risks in the context of the individual patient's predicament.

The term *evidence-based medicine* first appeared in the medical literature in 1991; it rapidly became something of a mantra. EBM is sometimes perceived as a blinkered adherence to randomized trials or a health-care manager's tool for controlling and constraining recalcitrant physicians. In fact, EBM and EBO involve informed and effective use of all types of evidence, but particularly evidence from the medical literature, in patient care.

EBM's evolution has included outward expansion—we now realize that optimal health-care delivery must include evidence-based nursing, physiotherapy, occupational therapy, and podiatry—and specialization. We need evidence-based obstetrics, gynecology, internal medicine, and surgery—and indeed, orthopedics, and neurosurgery. And of course, we need evidence-based orthodontics.

Applying EBO to management decisions in individual patients involves use of a hierarchy of study design, with high-quality randomized trials showing definitive results directly applicable to an individual patient at the apex to relying on physiological rationale or previous experience with a small number of similar patients near the bottom rung. Ideally, systematic reviews and meta-analyses summarize the highest quality available evidence. The hallmark of evidence-based practitioners is that, for particular clinical decisions, they know the strength of the evidence and therefore the degree of uncertainty.

What is required to practice EBO? Practitioners must know how to frame a clinical quandary to facilitate use of the literature in its resolution. Evidence-based orthodontic practitioners must know how to search the literature efficiently to obtain the best available evidence bearing on their question, to evaluate the strength of the methods of the studies they find, and to extract the clinical message, apply it back to the patient, and store it for retrieval when faced with similar patients in the future.

Traditionally, dental schools nor medical schools nor postgraduate programs have taught these skills. Although this situation is changing, the biggest influence on how trainees will practice is their clinical role models, few of whom are currently accomplished EBO practitioners. The situation is even more challenging for those looking to acquire the requisite skills after completing their clinical training.

This text primarily addresses the needs of both orthodontic trainees and specialist orthodontists. Appearing 20 years after the term *EBM* was coined, the text represents a landmark in a number of ways. It is the first comprehensive EBO text. The book represents a successful effort to comprehensively address the EBO-related learning needs of the orthodontic community and summarize the key areas of orthodontic practice.

The current text goes on to provide evidence summaries to guide the practitioner in each of the key common problems of orthodontic practice. Thorough and up-to-date at the time of writing, this text provides a definitive guide to evidence-based orthodontic practice today. That evidence will, of course, change, and in some areas change quickly. Clinicians must therefore use this book not only as a text for the present but also as a guide for updating their knowledge in the future. That future will, it is hoped, hold the advent of an evidence-based secondary journal similar to those that have been developed in other areas, such as *Evidence-Based Mental Health*, *Evidence-Based Nursing*, and the *ACP Journal Club*. These publications survey large numbers of journals relevant to their area and choose individual studies and systematic reviews that meet both relevance and validity screening criteria. These journals present the results of these studies in structured abstracts that provide clinicians with the key information they need to judge their applicability to the clinicians' own practices. Fame and fortune await the enterprising group who applies this methodology to produce evidence-based orthodontics.

Whatever the future holds for the increasing efficiency of evidence-based practice, the current text provides an introduction to a system of clinical problem solving that is becoming a prerequisite for modern orthodontic practice.

Gordon Guyatt

Contributor List

EDITORS

GREG J. HUANG, DMD, MSD, MPH, Associate Professor and Chair, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA

STEPHEN RICHMOND, BDS, DOrth RCS, MScD, FDSRCS, PhD, FHEA, Professor of Orthodontics, Dental School, University Dental Hospital of Wales, Heath Park, Cardiff, UK

KATHERINE W.L. VIG, BDS, MS, DOrth RCS, FDSRCS, Professor Emeritus, Division of Orthodontics, College of Dentistry, The Ohio State University, Columbus, OH

CONTRIBUTORS

DAVID R. BEARN, PhD, MSc, BDS, MOrth RCS, FDS (Orth) RCPS, FDSRCS, FHEA, Professor of Orthodontics, University of Dundee, Dundee, UK

PHILIP E. BENSON, PhD, FDS (Orth) RCS, MOrth RCS, MSc, PhD, FHEA, Reader/Honorary Consultant in Orthodontics, University of Sheffield School of Clinical Dentistry, Sheffield, UK

ANNE-MARIE BOLLEN, DDS, MS, PhD, Professor of Orthodontics, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA

JASON M. BRESSLER, DDS, BS, Research Associate, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA

BRIDGET DOUBLEDAY, PhD, MDentSci, BDS, MOrth RCS, FDSRCPS, Consultant Orthodontist, Forth Valley Royal Hospital, Stirlingshire, UK

PADHRAIG S. FLEMING, BDent Sc (Hons), MSc, MOrth RCS, FDS (Orth) RCS, Senior Registrar, Department of Orthodontics, Royal London Dental Institute, London, UK

JOSEPH GEORGE GHAFARI, DMD, Professor and Head, Orthodontics and Dentofacial Orthopedics, American University of Beirut Medical Center
Professor of Orthodontics, Lebanese University, Beirut, Lebanon
Adjunct Professor of Orthodontics, New York University, New York, NY

GEOFFREY M. GREENLEE, DDS, MSD, MPH, Clinical Assistant Professor, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA

x CONTRIBUTOR LIST

RAMZI V. HADDAD, DDS, MS, Instructor, Orthodontics and Dentofacial Orthopedics, American University of Beirut Medical Center, Beirut, Lebanon

STEFANIE HAMAMOTO, DDS, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA

LYSLE E. JOHNSTON, JR., DDS, MS, PhD, FDSRCS, Professor Emeritus of Dentistry, Department of Orthodontics and Pediatric Dentistry, The University of Michigan, Ann Arbor, MI; Professor Emeritus of Orthodontics, Department of Orthodontics, Center for Advanced Dental Education, Saint Louis University, St. Louis, MO

DONALD R. JOONDEPH, DDS, MS, Emeritus Associate Professor of Orthodontics, Department of Orthodontics, School of Dentistry, The University of Washington, Seattle, WA

GREGORY J. KING, DMD, DMSc, Moore Reidel Professor, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, UK

ANNE LITTLEWOOD, BA(Hons), MA, MCLIP, Trials Search Co-ordinator, Cochrane Oral Health Group, Manchester, UK

SIMON J. LITTLEWOOD, BDS, FDS(Orth)RCPS, MDSc, MOrth RCS, FDSRCS, Consultant Orthodontist, Orthodontic Department, St. Luke's Hospital, Bradford, UK

FRIEDERIKE LUTHER, BDS (Hons), FDSRCS, DOrth RCS, MOrth RCS, MSc, PhD, FHEA, Department of Orthodontics, Leeds Dental Institute, University of Leeds, Leeds, UK

STEVEN D. MARSHALL, DDS, MS, Visiting Associate Professor, Department of Orthodontics, University of Iowa College of Dentistry, Iowa City, IA

FRASER McDONALD, BDS, MSc, PhD, FDSRCS, FFDRCSI, Senior Lecturer and Honorary Consultant Orthodontist, Department of Orthodontics, King's College London Dental Institute, King's College, London, UK

DECLAN T. MILLETT, BDSc, DDS, FDSRCPS, DOrth RCS, MOrth RCS, Professor of Orthodontics, Dental School, University College Cork, Cork, Ireland

KEVIN O'BRIEN, BDS, FDS, DOrth RCS, PhD, Professor of Orthodontics, School of Dentistry, University of Manchester, Manchester, UK

MARIA E. SAADEH, DDS, MS, Clinical Associate, Orthodontics and Dentofacial Orthopedics, American University of Beirut Medical Center, Beirut, Lebanon
Clinical Instructor, Lebanese University, Beirut, Lebanon

JONATHAN SANDLER, BDS (Hons), MSc, FDSRCPS, MOrth RCS, Consultant Orthodontist, Chesterfield Royal Hospital, Chesterfield, UK

WILLIAM SHAW, BDS, MScD, PhD, FDSRCS, DOrth RCS, DDOrth RSCP, University Dental Hospital of Manchester, Manchester, UK

DAVID L. TURPIN, DDS, MSD, Moore/Riedel Professor of Orthodontics, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA

BELINDA J. WELTMAN, BHsc, MSc, BDent, MS (Orth), FRCD(C), Vancouver, BC

ROBERT J. WEYANT, MS, DMD, DrPH, Professor and Chair, Department of Dental Public Health and Information Management, School of Dental Medicine, University of Pittsburgh, Pittsburgh, PA

HELEN V. WORTHINGTON, BSc, MSc, PhD, Professor of Evidence Based Care, School of Dentistry, The University of Manchester, Manchester, UK

ALEXEI ZHUROV, PhD, Research Officer, Dental School, Cardiff University, Cardiff, UK

Evidence-Based Orthodontics

Part 1

Principles

A Historical Perspective of Evidence-Based Orthodontics

Katherine W.L. Vig, BDS, MS, DOrth RCS, FDSRCS

Professor Emeritus, Division of Orthodontics, College of Dentistry, The Ohio State University, Columbus, Ohio

Introduction

The unmanageable amounts of health-care information that had become available toward the end of the twentieth century created a serious challenge to clinicians trying to make informed decisions for their patients about the relative effectiveness of various treatment options. The lack of systematic assessments of the literature led to delays in the incorporation of better treatments as less effective, less efficient, and even harmful interventions continued to be recommended.

In response to this problem, medicine pioneered an evidence-based approach to clinical practice, which in 1972 was spearheaded by the British epidemiologist Archie Cochrane and described in his influential monograph entitled *Effectiveness and Efficiency* (Cochrane 1971). The impact of this new concept in clinical medicine—that all treatment interventions must be proven to be effective—was supported by the early example in which data was combined from clinical trials that investigated premature births. By 1974 all controlled trials in perinatal medicine had been systematically identified in a clinical trials register and by 1987, the year before Archie Cochrane died, 600 systematic reviews on health-care topics had been conducted. How one man, whose ideas were initially unacceptable to the medical community, had such a profound impact on medicine is recounted in the autobiographical monograph *One Man's Medicine* (Cochrane 1989). His revolutionary observations and convictions were fashioned by his experiences growing up in Britain during the tumultuous years surrounding two world wars and the introduction in 1948 of the British National Health Service.

Archie Cochrane and Development of Evidence-Based Medicine

The Early Years

Archie Cochrane was born in a small town in Scotland in 1909 to a privileged and wealthy family. His successful grandfather and great-grandfather pioneered the textile industry and benefited from the manufacture of the popular Scottish tweeds. As a young boy with an elder sister, two younger brothers, and devoted parents, he lived an affluent but disciplined life in a large house with multiple servants. His youthful world was disrupted in 1914 when the First World War was declared. His father joined a Scottish regiment and was killed in 1917 while attempting to rescue a wounded brother officer. Archie Cochrane was 8 years old and now carried the responsibilities of being the eldest son with three siblings and a grieving mother. The desolation of the loss of his father was followed by the death of his younger brother to tuberculosis and the severe wartime restrictions. He was educated in the traditional upper-class prerogative of “building character” by sending young boys to preparatory boarding school, followed by their prestigious and expensive “public” school before entering university. Archie Cochrane excelled in athletics and mathematics, and his aptitude for literature resulted in his successful admittance to King’s College, Cambridge. A rugby football accident curtailed the time he devoted to acting, riding, tennis, and golf but made him focus on his studies; he graduated with a double first-class honors degree. His grandfather’s death, while he was at Cambridge, resulted in his becoming independently wealthy early in his adult life, which he believed contributed to his later success. However, this was also the time of another family tragedy when his remaining younger brother died in a motorcycle accident. Archie was now the eldest and only son of his family, and he undertook responsibility for his widowed mother and elder sister.

The Influences in Developing an Evidence-Based Approach

Archie Cochrane was a man of the turbulent 1930s who witnessed the events leading to the Second World War. He was an emotional and intellectual individual whose independence and conviction of moral values caused him to often reject political solutions. When he was a medical student at University College Hospital in London, the Spanish civil war broke out, and Archie Cochrane risked his life by volunteering to join the Medical Aid Unit to Spain following Franco’s invasion. A year later he returned to England to complete his medical training while believing fascism a menace to Western civilization.

His experience of seeing the consequences of war prepared him for joining the British Army during the Second World War and serving overseas. His fluency and aptitude for languages, including German, French, and Spanish, resulted in his joining a commando regiment that included 70 Spanish refugees from the civil war who had enlisted in the British Army. The regiment was deployed to Crete where Archie was captured by the invading Germans. He spent the next 4 years as a prisoner of war (POW), serving as the medical officer to a camp of 20,000 prisoners from diverse multicultural backgrounds and countries whom he cared for with compassion and fortitude (Doll 1997).

This ordeal resulted in his abiding beliefs in patient care and that medical interventions that should be available for all individuals whatever their circumstance. As the medical

officer in the POW camp he had no privileges, sharing the same conditions, day and night, with his fellow prisoners. His courage and endurance as a compassionate medical officer sharing the same diet as the other POWs in the camp resulted in his first clinical trial. He was emaciated and jaundiced himself, with pitting edema above the knees, but he set up a trial with yeast he had acquired from the German prison guards. He describes this as “my first, worst, and most successful clinical trial” (Cochrane 1984).

Having survived the Second World War, he subsequently spent time in the United States before returning to England with a mission and commitment to change the imperfect British medical system. His firm belief in finding evidence for the effectiveness of medical interventions resulted in the development of randomized clinical trials (RCTs) and systematic reviews of the scientific literature. This initiated a new era in medicine—one that would ultimately influence dentistry. A new evidence-based approach to patient care was destined to revolutionize clinical practice, and the methodology had its roots in his experiences as a POW medical officer with limited medical supplies, never knowing what might or might not work. This uncertainty proved to be fertile ground for Archie to test his theories, as it allowed him to ethically randomize patients to varying treatments. This randomization usually resulted in well-matched groups that received different interventions, thus allowing the investigation of the most effective treatment.

The Cochrane Legacy

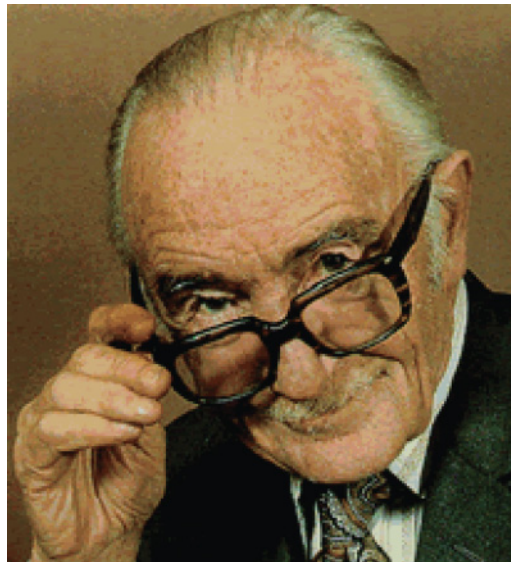


Figure 1.1 Professor Archibald Leman Cochrane, CBE FRCP FFCM, (1909–1988). The Cochrane Collaboration is named in honor of Archie Cochrane, a British medical researcher who contributed greatly to the development of epidemiology as a science. (Photo courtesy of The Cochrane Collaboration.)



Figure 1.2 The Cochrane Collaboration logo. The outer blue semicircles represent The Cochrane Collaboration and the inner circles the globe to represent international collaborations. The forest plot of clinical trials represents the effectiveness of administering corticosteroids to pregnant women delivering prematurely; the diamond to the left of the “no effect” line indicates meta-analysis favored the intervention.

The Cochrane Collaboration was established a year after Archie Cochrane’s death and is recognized in the 21st century as an international organization that prepares, maintains, and promotes accessible systematic reviews of the effectiveness of health-care interventions from which well-informed decisions may be made (Antes and Oxman 2001). The familiar logo of The Cochrane Collaboration (Figure 1.2) exemplifies and recognizes the impact of Archie Cochrane’s life. The circle, representing the global and international collaboration, encircles the forest plot, which depicts the results of a quantitative meta-analysis. This particular forest plot represents one of the earliest systematic reviews and meta-analyses of the literature on the therapeutic intervention of corticosteroids in women who were to deliver their babies prematurely. By a statistical combination of data from the clinical trials, the highest evidence, and ultimately the gold standard for clinical practice in caring for pregnant women delivering prematurely, was established. The benefits of the effectiveness of administering perinatal corticosteroids were undeniably correlated with the outcome of perinatal and neonatal survival with a consequent reduction in mortality and morbidity.

The Cochrane Collaboration

The Cochrane Collaboration (<http://www.cochrane.org>) has influenced and driven the science and methodology of systematic reviews and has been compared to the revolution-

ary Human Genome Project in its potential implications for contemporary health care (Naylor 1995). Nevertheless, changing the standard of care in clinical practice does not move quickly, and information gained from research experience has a long time lag before it becomes incorporated into clinical practice.

Historically, medical and dental regimes have remained unchanged even when well-designed clinical trials have provided counterevidence. Treatment decisions based on clinical experience and beliefs are extremely difficult to change, and it has been shown to take an average of 17 years for the findings from clinical trials to be implemented into clinical practice (IOM 2003). For example, thrombolytic therapy, and the administration of streptokinase, had clinical trials in 1960. By 1975 forty randomized clinical trials (RCTs) had been conducted, and by 1985 there were 50,000 patients enrolled, with evidence that thrombolytic therapy was effective. When a systematic review and meta-analysis conclusively showed the effectiveness of thrombolytic agents, it was finally accepted as a standard of care in 1990. If the contemporary methodological approach to evidence-based practice had been established 30 years previously, many lives could have been saved. Still, even when evidence is convincing, clinicians may find it difficult to relinquish their beliefs based on their clinical experience.

The Influence of an Evidenced-Based Approach

The establishment of the evidence-based approach resulted in rapid changes in the health-care system and in the education of students and residents in the health-care professions. A paradigm shift had occurred from the paternalistic choice of a treatment intervention by doctors for their trusting patients to a partnership in which the doctor and patient make choices together to determine the “best” treatment. It was therefore incumbent on the health-care provider to have knowledge of the best available evidence pertaining to the risks, costs, benefits, burden, and probability of success for various treatment options. The caveat was that if evidence exists to support the effectiveness and efficiency of treatment interventions, an integration of the best research evidence with clinical expertise and patient values and preferences should occur (Sackett DL et al. 1991, 2000).

The Application of Evidence-Based Dentistry to Orthodontics

One method of achieving an evidence-based approach in dentistry and its advanced specialty programs is to carry out a systematic review of all randomized clinical trials (RCTs) from which a quantitative analysis of the available data can be statistically included into a meta-analysis. This approach was developed in medicine with the benefit of patients and doctors making informed decisions on the most effective treatment intervention. The basis of a systematic review is that it provides a method of identifying all the available literature on a topic and synthesizing it into an easily accessible knowledge base from which the clinician is able to make informative choices and decisions. As this approach became accepted in dentistry leaders in the field developed a Cochrane Oral Health Group.

The Cochrane Oral Health Group/Collaboration

In 1996 the establishment of the Cochrane Oral Health Collaboration (<http://www.ohg.cochrane.org>) was initially based at Harvard University in Boston, Massachusetts, USA, but in 1997 was relocated to the University of Manchester in England. (see chapter 17, “Evidence-based Care in Context.”) The Cochrane Oral Health Group is part of The Cochrane Collaboration based in Oxford, England, and comprises an international network of researchers involved in producing and disseminating systematic reviews of controlled RCTs in the field of oral health. Searching for trials information to include in systematic reviews is a complex process; in order to avoid bias in the results of the review, it is important to include as many relevant trials as possible. (See Chapter 3, Electronic Searching for Clinical Trials Information.) The search process relies on initially defining the question, and this has been described in detail in Chapter 2, Clinical Research Designs. Finding the best available evidence from sources of published and unpublished studies requires a standardized systematic approach to avoid the different types of recognized bias (Egger, Smith & Altman 2001). The quality of data retrieved from a careful, systematic, and standardized review of the scientific literature may be quantitative and/or qualitative in nature (Glasziou et al. 2001). Therefore discrete steps to find the relevant studies are required in searching computer databases to retrieve a body of literature that then requires careful selection and appraisal.

Evidence-Based Dentistry

Dentistry did not adopt this revolutionary concept in guiding clinical practice and the education of dental students and residents in the advanced specialty programs until the mid-1990s. To a certain extent it was forced on the profession by several events that occurred in 1995 owing to the publication of “Dental Practice Parameters for Oral Health” (McNeil et al. 1995). The ADA dental practice parameters stressed the need to develop and implement aids to assist in clinical decision making which were cited as the need for

- condition-based parameters, not procedure-based,
- integrated oral health care in an interdisciplinary approach,
- parameters to aid clinical decision making,
- process of care to be emphasized as well as the outcome,
- balancing patient needs with scientific soundness.

In the same year, The Institute of Medicine Report (Field 1995) was published on the future of dental education. This had 22 recommendations, which among others, emphasized the need to implement

- evidence-based care,
- patient-centered treatment,
- elimination of unnecessary/ineffective treatment interventions,

- scientific evidence, outcome research, and formal consensus processes in clinical practice guidelines,
- research to evaluate outcomes of alternative treatments.

With the need to make major changes in the practice and education of oral health-care professionals, at the end of the 20th century the Pew Trust also identified the critical challenges necessary for health-care professions (Pew Health Professions Commission 1995).

Making Rational Decisions in Orthodontic Practice

In orthodontics, clinical experience suggests that some conditions are best treated early for biological, social, or practical reasons, whereas others should be deferred. So how do we reconcile these conflicting issues? When anterior crossbites exist in the early mixed dentition due to a Class I crowded dentition or with a mild developing Class III skeletal pattern, should we wait until the permanent successors have erupted in the late mixed dentition or correct earlier to avoid perpetuating the malocclusion with possible labial gingival recession on the mandibular incisor from the traumatic incisor relationship (Vig et al. 2007)? When using a protraction face mask in an attempt to move the nasomaxillary complex forward, our knowledge of craniofacial growth and development indicates early intervention when the circum-maxillary suture system should be responsive. Correcting the anterior crossbite early supports the concept of effective and efficient early treatment intervention. However, with further growth the Class III tendency may result in the anterior crossbite being reestablished. Problems exist when using an evidence-based approach to clinical decision making in orthodontics, as the scientific literature in our specialty has relatively few prospective RCTs, and this study design is considered to provide the highest level of evidence.

So how are clinical judgments made when they cannot be based solely on evidence at the highest level but rather rely on lesser-quality studies and/or clinical experience? One of the most common early orthodontic treatment interventions is the correction of posterior crossbites in the mixed dentition, which may be considered a well-accepted clinical practice. But what evidence exists in the scientific literature? A systematic review published by Harrison and Ashby (2001), “Orthodontic treatment for posterior crossbites,” resides in the Cochrane database of systematic reviews. This is a very comprehensive review of randomized and controlled clinical trials in the scientific literature that reported data on the outcomes of crossbite correction. An extensive number of publications on this topic exist, but until a systematic approach was made to review the literature and identify the quality of studies that should be included, stronger inferences could not be made. The result of the search strategy to identify studies of orthodontic treatment for posterior crossbites, limited by a priori inclusion criteria, resulted in only seven RCTs and five controlled clinical trials. Cochrane reviews have the advantage of being regularly updated as new information becomes available. The updated abstract included studies since 2001, and for this update 113 abstracts were assessed for potential inclusion. Of these, 38 papers were obtained and assessed for eligibility. An additional 5 reports for three RCTs and one controlled clinical trial (CCT), together with another report to a previously included CCT, satisfied the inclusion criteria.

It becomes clear when trying to quantify the evidence using systematic reviews and meta-analyses that a definition of evidence-based clinical practice requires the careful and considered use of statistics and may be defined as “. . . the enhancement of a clinician’s traditional skills in diagnosis, treatment, prevention and the related areas through the systematic framing of relevant and answerable questions and the use of mathematical estimates of probability and risk” (Donald & Greenhalgh 2001). The advantage of a systematic review is that it will limit bias by a methodological approach to strict inclusion criteria of articles, and the conclusions are more reliable and accurate (Greenhalgh 2001). This is covered in Chapter 2, Clinical Research Designs, and Chapter 19, Reflections on a Decade of Evidence-Based Dentistry.

Even when evidence is available, clinicians may still be unable to relinquish their beliefs based on their clinical experience. In orthodontic clinical practice, treatment decisions are made based on early intervention for Class II patients being beneficial, even when evidentiary data does not appear to support the effectiveness, efficiency, and benefits of this approach. (See Chapter 4, The Treatment of Class II Malocclusion.) Orthodontics, while the oldest specialty in dentistry, recognizes that strong scientific evidence is an important goal for the future of the profession. However, patients are waiting to be treated even though we cannot provide good estimates for the outcomes of alternative treatments at the time of the consultation. In the face of this uncertainty, it becomes even more important for patients to have their preferences considered during the treatment planning stage.

Advances are often first brought to our attention by anecdotal case reports and observation, as was the discovery of penicillin. Although low on the strength of evidence, these initial reports still have value, as do case series, retrospective studies, and clinical experience. Although there is a paucity of clinical trials in orthodontics from which systematic reviews may be conducted, the methodology is still relatively new. In medicine there was also considerable opposition to Archie Cochrane’s insistence that clinical trials needed to be done to establish evidence for the effectiveness of clinical interventions. The lack of RCTs in orthodontics does not mean we should accept the present state of orthodontics as a science but rather that we should demand more rigor in designing clinical trials to determine what works, what doesn’t work, and what is just inspired rhetoric with little scientific support or substance. If the very expensive RCT cannot answer the question/hypothesis we would like to test, then perhaps well-designed cohort studies should be a starting place.

The American Dental Association Website

The initiative by the American Dental Association (<http://www.ada.ebd.com>) to develop a website for both clinicians and the public to access current information has provided a rich resource to search for the best information we have concerning alternative treatment interventions. By identifying authors who are publishing in a field of interest, it is possible to easily contact, communicate, and collaborate with researchers all over the world. Research cannot be set up overnight, but undertaking a systematic review on a chosen topic will allow areas of strength and weakness to be identified. This will reveal further fertile research opportunities and stimulate the development of hypothesis-driven research.

The Future of an Evidence-Based Approach in Orthodontics

The future of the evidence-based approach will be discussed in Chapter 18, “Playing Doctor: Evidence-Based Orthodontics,” in which the author states “the limitations of evidence-based orthodontics’ decision process are the specialty’s attitude towards evidence and the quality of the evidence.” We now have the methodology available from which to design future clinical trials to generate more robust evidence for the effectiveness of treatment interventions.

Attacks on an evidence-based approach and severe criticism of clinical epidemiology and the evaluative clinical sciences embodied in health services research was in response to the impact and change in clinical practice standards. Doctors were urged to defend clinical reasoning based on the clinicians experience and their understanding of pathology and physiological mechanisms. If we cannot accept applying the highest level of evidence, we will be doomed to muddle along with our best guess. A choice needs to be made based on the alternative outcomes of a clinical intervention combined with the patient’s preferences and the clinician’s expertise. In the interest of providing the best available care to our patients, the current best evidence must be incorporated into the treatment recommendations that each clinician makes.

References

- American Dental Association. *Evidence-based dentistry* [Online] Available at: <http://www.ebd.ada.org> [Accessed November 10, 2010].
- Antes, G. & Oxman, A.D., 2001. The Cochrane collaboration in the 20th century. In: M. Egger, G.D. Smith & D.G. Altman, eds. *Systematic reviews in health care: meta analysis in context*. 2nd ed., New York: BMJ Books, Chapter 25.
- Cochrane, A.L., 1971. *Effectiveness and efficiency: random reflections on health services*. New York: BMJ.
- Cochrane, A.L., 1984. Sickness in Salonica: my first, worst and most successful clinical trial. *British Medical Journal*, 289, pp. 1726–1727.
- Cochrane, A.L. with Blythe, M., 1989. *One man’s medicine. an autobiography of Professor Archie Cochrane*. London: Cambridge University Press.
- Cochrane collaboration. [Online] Available at: www.cochrane.org [Accessed November 10, 2010].
- Cochrane Oral Health Group. [Online] Available at: <http://www.ohg.cochrane.org> [Accessed November 10, 2010].
- Doll, R., 1997. A reminiscence of Archie Cochrane. In: A. Maynard & I. Chalmers, eds. *Non-random reflections on health services research*. New York: BMJ Books, pp. 7–10.
- Donald, A. & Greenhalgh, T. 2001. *A hands-on guide to evidence-based health care: Practice and implementation*. Oxford: Blackwell Science.
- Egger, M., Smith, J.D. & Altman, D.G., 2001. *Systematic reviews in health care: meta-analysis in context*. 2nd ed., New York: BMJ Books.
- Field, M.J. 1995. *Dental education at the crossroads: challenges and change*. Washington DC: National Academy Press.
- Glasziou, P., Irwig, L., Bain, C. et al., 2001. *Systematic reviews in health care*. London: Cambridge University Press.

- Greenhalgh, T. 2001. Papers that summarize other papers (systematic reviews and meta-analysis). In: *How to read a paper. The basics of evidence based medicine*, New York: BMJ Books, Chap. 8, pp. 120–138.
- Institute of Medicine, 2003. Report to the National Academy of Science.
- Harrison, J.E., & Ashby, D. 2001. Orthodontic treatment for posterior crossbites. *The Cochrane database of systematic reviews*. Hoboken, NJ: John Wiley & Sons Ltd. Art.No.CD000979, p. 1.
- McNeil, K.J., Aurbach, F.E., Brotman, D.N. et al., 1995. Dental practice parameters; parameters for 12 oral health conditions. *Journal American Dental Association* (Suppl) 126, S1–S37.
- Naylor, C.D., 1995. Grey zones of clinical practice: some limitations to evidence-based medicine. *Lancet* 345, 840–843.
- Pew Health Professions Commission, 1995. Critical challenges: revitalizing the health professions for the twenty first century. The 3rd report of the Pew Health Professions Commission. San Francisco, CA.
- Sackett, D.L., Haynes, R.B., Guyatt, G.H. et al., 1991. *Clinical epidemiology: a basic science for clinical medicine*. 2nd ed., Boston: Little, Brown.
- Sackett, D.L., Strauss, S.E., Richardson, W.S. et al., 2000. *Evidence-based medicine: How to practice and teach EBM*. Edinburgh: Churchill Livingstone.
- Vig, K.W.L., O'Brien, K. & Harrison, J. 2007. Early orthodontic and orthopedic treatment. The search for evidence: will it influence clinical practice? In: J.A. McNamara, ed. *Early orthodontic treatment; is the benefit worth the burden*. Craniofacial growth series, 44, pp. 13–38. Ann Arbor, MI: Center for Human Growth and Development, University of Michigan.

Clinical Research Designs

Robert J. Weyant, MS, DMD, DrPH

Professor and Chair, Department of Dental Public Health and Information Management,
School of Dental Medicine, University of Pittsburgh, Pittsburgh, Pennsylvania

Introduction

Dr. Jones is an orthodontist who recently graduated from training and is now in private practice, having purchased her practice from a retiring orthodontist. After several months, Dr. Jones noted that she was receiving a large number of referrals from community general practice dentists of young children aged 7–9 who have prominent front teeth (i.e., Class II malocclusion). The referrals were implying that the young patients would benefit from early treatment, and most of these patients were told by their referring general dentists that if they received “early” treatment (by age 9), they could avoid more extensive treatment when they were older (in adolescence, after age 12). Dr. Jones was happy to have the referrals but was not sure she could tell the patients with confidence that they would be less likely to need orthodontic treatment as adolescents if they received “early” treatment now. Moreover, Dr. Jones was taught that both headgear and functional appliances were appropriate approaches for treatment of children with prominent upper front teeth but was not sure which approach would be best. Dr. Jones felt that she needed more information so that she could discuss treatment in an informed manner with her patients and make scientifically sound clinical decisions about recommending treatment.

The above vignette provides the reader with a common situation encountered frequently by clinicians, the need for additional, high-quality evidence from the scientific literature to assist them in their clinical decision making. In this mode, clinicians are consumers of the scientific literature as opposed to producers of science; consequently, they need a broad understanding of research methods and designs so that they can properly interpret the scientific basis for clinical practice. Whether orthodontics or any area of medicine is a science is debatable because the nature of the problems addressed by medical and dental care draws on ethics, culture, and economics in a way not commonly found in chemistry, physics, and biology. Nevertheless, as with all of biomedicine, orthodontics can thank empirical research for helping to refine and optimize contemporary approaches to patient care. The research underlying clinical practice ranges from basic sciences, such as genetics and physiology, to social sciences, such as psychology and sociology. All of these clinical evaluative sciences inform clinical practice, and all are fundamentally derived from the same overarching scientific process or method. At its best, research helps to improve the quality of care and patient outcomes, but when the science is poor or misunderstood, its misapplication can lead to just the opposite result. Hence, understanding the elements of good research and what makes science important to clinical practice is needed as a basis for clinical care. This chapter is designed to aid in this understanding.

The Scientific Method

The scientific method is, in fact, part of a broader area of philosophy known as *epistemology*. Epistemology is the branch of philosophy that deals with the nature of and limits to human knowledge (Salmon et al. 1992). A proper discussion of epistemology and the philosophy of science are well beyond the scope of this chapter. Suffice is to say that our concern in clinical practice is to have the best “knowledge” available to help our patients. There are many ways of humans “knowing” something, including intuition, faith, reason, authority, testimony, personal experience, and science. The distinction of importance here is between belief (I think something is true) and knowledge (something is actually true). Arguably, then, of all the ways we have of knowing something, the scientific method provides us with the best approach if our goal is obtaining objective, valid, and useful information.

Science pursues knowledge by essentially asking and then answering questions. Simple enough. But the devil is in the details. The veracity of the information generated by this process is entirely dependent on the rigor and objectivity employed in how one seeks out the information to answer the question. Moreover, the specific approach to answering the question, that is, the research design, places inherent limits on the conclusions (answers) that can be made. This chapter provides a brief overview of basic research development, the common clinical research designs, their uses, strengths, and limitations, and a discussion of best practices that apply broadly to any research endeavor. The intent is to provide a broad overview framed in terms related to clinical orthodontics.

Developing a Hypothesis

Although it is seemingly straightforward, asking the right question is key to moving science forward. The questions of science are derived from many sources, including intuition, clinical experience, and reading the scientific literature.

Any question that is focused on naturalistic answers (as opposed to metaphysical answers) is fair game for science. Some questions only serve to satisfy the questioner's curiosity, whereas other questions are the motivators that advance a scientific discipline. The degree to which a question is framed to address a gap in our general knowledge of a subject is the degree to which a question serves to motivate research and move science forward. These are questions that focus us on those areas that lie just beyond our current understanding of how things work. Consequently, science tends to move forward incrementally by constantly working at the frontier of our current understanding and carefully taking the next logical step forward. Scientists (and clinicians) working in a field generally know where that boundary is between current knowledge and our need for new information, and it is this knowledge that allows them to create new questions that lead to the research that advances the field.

Dr. Jones in the vignette has implicitly asked a question that derives from her clinical experience with her new patient population: Can early orthodontic treatment reduce or prevent the need for additional treatment later in adolescence?

Based on one's experience in an area, it is possible to offer a prediction of what the answer to a question might be. In science this provisional answer is referred to as a hypothesis. From the above example, Dr. Jones might hypothesize that early treatment will, in fact, reduce the need for later treatment for a substantial number of her patients. Any orthodontist understands this question, and most would have an opinion about the answer. In contrast, for naive individuals (i.e., non-dentists), not only would they not have an answer to this question, they also would be very unlikely to think of the question.

When asking a question about treatment outcomes, one is essentially asking about causality. Does treatment A cause outcome B? One of the fundamental goals of clinical research is to establish causality. In so doing we improve our understanding of underlying mechanisms and we provide an opportunity to design clinical interventions aimed at improving the quality of clinical care. In our example, Dr. Jones wishes to know if early treatment is causally related to subsequent occlusal status (and hence the need for additional treatment).

An important concept that underlies the notion of causality in clinical research is that most associations in biomedicine are probabilistic (stochastic) rather than deterministic. This means that at the level of clinically measured outcomes, the likelihood that some outcome will occur as the result of some exposure is not a certainty. For example, if someone is a life-long smoker, they are more likely to experience some sort of lung or heart problem than a nonsmoker. Not all smokers experience lung or heart problems, and some nonsmokers indeed develop these conditions, but smoking certainly increases one's chances of developing these problems. Consequently, assessing causality in probabilistic systems is challenging and requires an understanding of statistics and research methods. Moreover, this implies that the research must occur in populations (groups) of individuals (patients) as we are often attempting to detect only slight changes in the marginal likelihood of an outcome.

There is a rich philosophy underlying the notion of establishing causality that goes beyond the scope of this chapter. However, the philosophical discussion of causality can often be immobilizing when there is a pragmatic need to move forward with clinical decision making. Fortunately, there are well-regarded heuristic criteria that are considered, when present, to strongly suggest a causal association. Some of the criteria most widely used are guidelines first put forward in 1965 (Hill 1965) by Sir Austin Bradford Hill (1897–1991), a British medical statistician, as a way of evaluating the existence of a causal

Table 2.1 Hill’s viewpoints on the aspects of an association to be considered when deciding on causality.

Hill’s Viewpoint	Interpretation
Strength of association	The stronger the associations (larger effect size) between the hypothesized causal agent and the effect, the less likely the association has occurred by chance or is due to an extraneous variable (i.e., confounding).
Consistency	A relationship when observed repeatedly in different people or under different circumstances increases the likelihood of it being causal.
Specificity	An effect is the result of only one cause. In Hill’s day this was considered more important than today.
Temporality	It is logically necessary for a cause to precede an effect in time.
Biological gradient	This is also known as a dose-response relationship and implies that as the exposure to the causal agent increases, the likelihood of the effect occurring increases.
Plausibility	The causation we suspect is biologically plausible. However, Hill acknowledged that what is biologically plausible depends upon the biological knowledge of the day.
Coherence	Data should not seriously conflict with the generally known facts of the natural history and biology of the disease.
Experiment	Experimental evidence provides the strongest support for a causal hypothesis.
Analogy	At times, commonly accepted phenomenon in one area can inform us of similar relationships in another.

Source: Hill (1965).

link between specific factors. He wished to avoid the philosophical and semantic problems often encountered in discussions of causality and rather move to the pragmatic situation in which those aspects of an association that, if present, would most likely lead to the interpretation of causation (Hill 1965). His “viewpoints” (see Table 2.1) are put forward as suggestions and specifically were not called criteria for estimating causality. With the exception of the temporal association (i.e., the cause must precede the outcome), all of these are conditions that suggest but are not required when making the case for a causal association. It should be noted that Hill is not the only person to suggest such factors, but his are the most widely recognized.

Testing a Hypothesis

Testability is the hallmark of a well-structured hypothesis and the foundation for high-quality scientific investigation. Although the philosophy underlying the testing of hypotheses is beyond the scope of this text, the common approach is based on deduction and extends from the work of philosopher Karl Popper. This approach is known as *refutation*

or falsifiability. Falsifiability means that a hypothesis can be shown to be false through observation or experimentation.

To make a hypothesis fully testable, it must go through a process of operationalization. This means that all of the elements of the hypothesis must be specified in such a way that will allow them to be measured. Moreover, it also implies the need for some a priori determination of what constitutes the standard by which the hypothesis will be declared, “falsified.”

Once the hypothesis is fully operationalized, the investigator can then move forward with the empirical investigation, the aim of which is to attempt to falsify his or her hypothesis. If successful in demonstrating that the hypothesis is false, then that hypothesis should be discarded and, ideally, a new hypothesis, benefiting from this new information, created and the process repeated. Failing, through rigorous effort, to demonstrate that a hypothesis is false does not necessarily demonstrate that it is true, but it provides the initial evidence that it may be true.

It is rarely the case that a single study is considered definitive proof of the veracity of a hypothesis. Rather, each experiment (or observational study) done to test a hypothesis provides evidence that supports or refutes the hypothesis. Over time, this so-called weight of evidence accumulated through multiple investigations, often by different investigators, provides a sense of the veracity of the hypothesis. Consequently, most knowledge created through the scientific process is considered provisional. Some say that hypotheses should not be defined as true or false but rather as useful or not useful in accurately predicting outcomes.

In the example above, Dr. Jones as an orthodontist in full-time private practice would not likely address her desire to know more about the association between early treatment and its effect on later treatment need through her own research efforts. Rather she would likely search for publications where this issue has been studied. Her ability to understand the elements that go into creating high quality clinical research and what types of research designs are used to test various types of hypotheses will give her the knowledge necessary to select and critically evaluate appropriate publications for consideration.

Research Quality Issues

Even the casual student of science appreciates that science demands carefully constructed and objective processes be used in generating information (data) to test (falsify) hypotheses. All well-designed clinical research shares common features that serve to reduce bias and ensure valid findings. These features are mentioned in brief here, and interested readers can find more detailed information in the recommended readings at the end of the chapter.

Measurement Issues

Accurate measurement is a hallmark of good science. Poorly selected or designed measures lead inevitably to the inability to properly test a hypothesis and ultimately to spurious results. Thus, great care is required when operationalizing a hypothesis to ensure that all of the important elements of the hypothesis can be measured in a valid and reliable manner. In the example, the notion of malocclusion needs to be defined—a case definition. This should include a detailed definition of what elements (e.g., overjet, overbite, ANB, etc.)

will be included and exactly how they will be measured. Similarly, “early treatment” will need to be defined in terms of age, duration, forces, and appliances to be used.

Population (Study Subjects)

The subjects or participants in a study (including any control or comparison group) need to be defined with respect to all relevant demographic and biomedical characteristics. In the example, age and orthodontic status would be important to consider, whereas gender and race would perhaps be less so. Inclusion and exclusion criteria need to be clearly specified and based on a sound rationale. Descriptions of the population serve to provide important information on study relevance to readers.

A related issue is the use of a control or comparison group. This is of extreme importance if we are to conclude that an intervention has had an effect. If the treatment and control groups are not similar, then it can be difficult to conclude that the treatment was the causative agent for any outcome. In experimental studies this is often accomplished through randomization.

Data acquisition needs to be carefully considered to assess feasibility. Failure to be able to accurately collect relevant data has been the downfall of many clinical studies. If the forces applied by headgear cannot be measured in the study in a valid manner, it will be impossible to determine the association between the treatment and outcome. In cases of rare conditions, the inability to accumulate enough subjects can lead to underpowered studies.

Statistical Analysis and Sample Size

Choosing the right approach to statistically analyze study results is crucial for obtaining a valid test of the hypothesis. Given the complexity of making an appropriate choice for statistical analysis in most modern clinical studies, successful analysis will hinge to a great degree on the inclusion of a well-trained research methodologist from the beginning to the end of the study.

A related issue that also hinges on the advice of a research methodologist is the sample size, or number of subjects to be included. There needs to be a sound rationale provided for the sample size selected. Moreover, in negative studies (studies that fail to show support for the hypothesis) a post hoc power estimate is important. The reader should be informed if the study’s failure to find a significant result was based on the validity of the hypothesis or the inadequacy of the study design. The appropriate number of subjects to be included in a study cannot be determined in the abstract as it is dependent on features of the study design, actual effect size of interest (clinically important), expected variability in the data, and approach to analysis.

Placebo

A placebo is a material, formulation, or intervention that is similar to the test product or procedure, but without the use of an active ingredient or efficacious process. The “placebo effect” is the degree to which a benefit (or harm) is experienced by a study subject when a placebo, rather than an active ingredient or process, is used in an experimental study. The degree of benefit experienced as the result of the use of a placebo can be substantial and hence must be considered when evaluating the efficacy of a therapeutic intervention.

Placebo effects are greatest for outcomes that are highly subjective or psychogenic in nature (e.g., mood changes, pain sensation) and are negligible for things that are not under psychological control (e.g., reduction of overjet after nonapplication of orthodontic forces). It is considered good practice to employ a placebo when practical and ethical. When a placebo effect occurs, it serves to reduce the effect size and consequently requires a larger sample size to evaluate the efficacy of an intervention.

Duration

The need to conduct a prospective study for a sufficient length of time to observe the anticipated outcome is another issue related to feasibility and study cost. The study must run for long enough to observe the development of the outcome of interest. In caries studies, perhaps 2 years would be needed. For orthodontic relapse, perhaps much longer follow-up is needed.

Research Designs

In addition to establishing a hypothesis, ensuring that all variables therein can be accurately measured, and having access to an appropriate population of subjects, the best research design to use to test the hypothesis is a major decision for an investigator. The strengths and weaknesses inherent in every design will determine how well the hypothesis can be tested and what conclusions can be made at the end of the study. The selection of design is based on factors related to the hypothesis being tested as well as feasibility, ethical concerns, budget, and often other factors. Some questions readily suggest an appropriate design. For example, evaluating the efficacy of a new treatment is generally done using a randomized controlled trial (RCT), whereas disease prevalence studies are done using a cross-sectional design. The initial investigation of etiology is often done using a case-control design. The section below briefly introduces the most common designs used in clinical research and lists their uses, strengths, and weaknesses. (See also Table 2.2) This list is not comprehensive, as hybrid and quasiexperimental designs are not included. But a general understanding of the four designs listed will illustrate important concepts

Table 2.2 Research designs ordered from least potential for bias (top) to greatest potential for bias (bottom).

Meta analyses
Systematic reviews
Experimental trials (RCT)
Cohort studies
Case-control studies
Human trials without controls (quasi-experiments)
Cross-sectional studies
Simple descriptive studies
Case reports
Personal opinion

and give the reader a good introduction for understanding the majority of what is encountered when reading the orthodontic literature.

Research designs can be divided into two groups, experimental and observational, based on the degree of control the investigators exert over the conditions of the study. Experimental studies are those for which the investigators actively manipulate the conditions under study, for example, when the investigator gives some of the study subjects a therapeutic intervention. Observational studies are those for which there is effectively no manipulation of study conditions by the investigators. Rather, investigators simply observe and measure conditions that occur within the subjects.

The ability to assign study subjects, especially through use of randomization (e.g., RCT) and the ability to closely measure important aspects of the exposures and outcomes (e.g., RCT and cohort) of a study can greatly reduce bias and, when possible, are the preferred designs for testing hypotheses about causality.

Space allows only the most basic description of each of the research designs. Each design on its own been the topic of full texts, and interested readers can find references at the end of the chapter. The vignette above can be used to show how various clinical questions can relate to research designs.

Imagine that Dr. Jones has the following questions relating to the uncertainty over early treatment:

1. How many children in the community are affected by early malocclusion of this type (Class II)?
2. Is thumb sucking a risk factor that could increase the likelihood of Class II malocclusion?
3. What proportion of children with early Class II malocclusion would grow out of a need for orthodontic intervention if they did not receive early treatment?
4. Is headgear more efficacious than functional appliances for early treatment of Class II malocclusion?

Observational Research Designs

Cross-sectional

Question 1 above is a question of disease prevalence and would best be addressed through a cross-sectional study. Cross-sectional studies are the most common observational research design used in clinical and epidemiological research and are used to estimate disease prevalence and to explore relationships between variables through correlational analysis.

The cross-sectional design can be either descriptive, such as a prevalence study, or analytic, such as a study correlating risk factors and disease status. DeAngelis (1990) notes that the name *cross-sectional*, “comes from the image of taking a slice across a stream of activity that is flowing from some point of onset toward some outcome.” This all-at-once approach to gathering data provides the design’s greatest strengths and weaknesses.

The strength of the design includes its relative low cost, as there is no need to follow up with subjects. It is also possible to screen large numbers of variables, especially when a questionnaire or record review approach is used to collect data. The study duration is

also often quite short in cross-sectional designs, with all data immediately available for analysis after the one phase of data collection.

The major weakness of the design also comes from the all-at-once nature of the data collection because the temporal relationships between variables can be confused. Hence, this design is not considered optimal for assessing causal associations. Additionally, the external validity of the study, the ability of the investigators to draw conclusions about a larger group of interest beyond just the study subjects, is based on the quality of the sampling process used to select study subjects. If the selection of study subjects is done well, cross-sectional studies can have high external validity.

Other uses of the cross-sectional design include opinion (survey) research and normative values studies (e.g., Bolton 1958).

Given the weakness in establishing causal associations, these studies are often used as a means for creating new questions or for hypothesis generation rather than for testing hypotheses. Correlations found in cross-sectional studies in general should be followed up in subsequent research using other designs that allow for better characterization of the hypothesized association with regard to the conditions indicating causality, as noted by Hill (1965).

Case-Control

The case-control design is a versatile one that is often used as an initial exploration of etiology, hence appropriate for question 2 above. A case-control design should begin with a statement about the source population giving rise to the so-called cases (Rothman and Greenland 1998). In the example, cases would be defined as children with Class II malocclusion, and the source population could be something such as all children living in Dr. Jones's community between the ages of 7 and 9. The control group would also be selected from this source population and would be children without the condition (no Class II malocclusion).

The design is considered retrospective in that the exposures of interest (potential etiological factors) will all have occurred prior to the initiation of the study and are collected through historical assessment (e.g., record review, questionnaire, subject interview). In this example, it could be hypothesized that thumb sucking could be a risk factor, and parents could be asked questions about their child's past habits in an interview or with a questionnaire.

The advantage of this design is the fact that you start the study by enrolling subjects who already have the condition or outcome of interest (e.g., Class II malocclusion). Hence, diseases that are rare or have long latency periods (e.g., certain cancers) can be efficiently studied without the need to recruit large numbers of subjects (when diseases are rare) or waiting for decades for an outcome to develop (when diseases have long latency periods). However, this design is not limited to rare disease or those with long latency.

Since the exposures that potentially could have resulted in the outcome have already occurred, this design also sidesteps any ethical concerns about exposing study subjects to potential harm or not providing needed care in the quest for information on etiology. Thus, this is a commonly used design in the study of toxic exposures leading to diseases such as cancer.

There are two main concerns with the case-control study design. One is information bias based on poor recall or documentation of past exposures. It may be difficult to

accurately recall past exposure for many subjects, particularly when they occurred far in the past or when they are not readily quantifiable. In the example, some measure of the concept of “thumb sucking” would need to be developed and used to evaluate the exposure level for each child.

The second, and often the greater concern is the bias introduced by poor selection of the control group. Selecting an appropriate control group is far from a trivial task and can be the downfall of a case-control study through the introduction of uncontrolled selection bias. Rothman and Greenland (1998) and Sackett (1979) address these biases at length and provide insight into strategies to overcome them.

Cohort

This prospective design consists of assembling a group of subjects who, at the time of study initiation, are free of the outcome (disease) of interest but vary in their exposure to the potential etiological agents of interest. The individuals are then followed over time by periodically reassessing the subject to determine if and when the outcome develops. The study must run until sufficient numbers of individuals develop the outcome to be able to statistically analyze the results or until some critical phase has passed. These designs are the preferred observational design when examining causal associations and can also be used to study the natural history of a disease. Thus, this is the design of choice when determining question 3 above, how many children will grow out of a need for orthodontic treatment if they remain untreated.

Cohort studies often create a rich and complex dataset that allows for numerous hypotheses to be tested. Since much of the measurement of the exposures of interest are done by the investigators (rather than through record reviews or subject recall), the design is considered to be the observational design with the lowest potential for bias. Moreover, conclusions related to causality are strengthened by the ability to establish the temporal association between exposure and outcome. Given that the investigators do not control exposures among the study subjects, the ethics of studying harmful exposures (e.g., smoking) are avoided.

The main weaknesses of this design are its cost to assemble and follow a cohort, often for years, with subjects lost to follow-up as the study unfolds, and the potential for other causal factors confounding the results, since exposures are not randomized or controlled.

Experimental

Randomized Controlled Trial

The randomized clinical trial (RCT) is the sine qua non for establishing efficacy and safety of therapeutic interventions and would be the design of choice for question 4 above. Since its development in the 1950s (Randal 1998), the methods have undergone refinement, with current best practices for RCTs formalized in the *Consolidated Standards of Reporting Trials* (CONSORT) statement (Altman et al. 2001). Details of this potentially complex design can be found in Meinert (1986). This is the obvious choice to address question 4 above.

In its simplest form, the RCT is a means to compare two approaches to treating a given condition or disease. The first step requires recruiting a population of individuals, all of whom have the condition or disease of interest. This group is then divided into two groups through a formal randomization process, the purpose of which is to make the groups as

similar are possible with respect to all potential factors that could be related to their response to the treatment(s) under study. Randomization involves assigning individuals to one of the study groups through a random process to maximize the probability that study groups are similar as to disease status, as well as medical, demographic, social, or other relevant conditions, and independent of the investigators' knowledge of subjects. Once the two groups have been assembled through randomization, it can be assumed that any difference in response to the two therapies under study is related to the efficacy of the therapies and not to some underlying difference in the two groups (e.g., age, disease severity, or comorbidities).

Each study group is provided with a different therapy. Generally RCTs are used to compare a "new" therapy to a traditional therapy, but in some cases it is ethical to compare a new therapy with no treatment or placebo. The decision on what is the proper comparison therapy with a new therapy is based on ethical considerations and the current standard of care. When a new therapy is introduced, its assignment to patients in an RCT is considered ethical only when there is a state of equipoise. *Equipoise* is a state of presumed equality between the new therapy and the old, where it is truly unknown if the new therapy offers any benefit (or harm) compared to the old. It is only when the condition of equipoise exists that it is considered ethical to randomly assign patients into the new or traditional treatment groups. When a current efficacious therapy exists, new therapies must be compared with current therapies. Only when no current efficacious therapies are available can a "no treatment" or "placebo" group be used.

Once the groups are assigned and the therapies initiated, the study subjects are followed over time to determine how well the therapies did in treating the condition of interest. At the same time, unwanted outcomes (adverse events) are monitored to ensure subject safety and determine the hazards of the new therapy. For any research funded by the National Institutes of Health, a data safety and monitoring board (DSMB) needs to be in place to ensure that any harm arising from the therapies under study is noted and, if necessary, the study can be stopped to prevent further subject harm.

The advantage of the RCT is its ability to minimize bias. Bias is minimized through the construction of two equal groups for study assembled through randomization. Additionally, the investigators can exert careful control over the delivery of the therapeutic intervention and can carefully monitor the changes in subject health status. Thus, it is unlikely that any outcomes that are observed are the result of uncontrolled bias. Consequently, RCTs are said to have high internal validity (internal validity is defined as the degree to which a study provides truth about a cause-and-effect relationship within the study sample).

The major disadvantages of the RCT are its cost and, at times, low external validity (external validity is defined as the ability to generalize the findings from the study to a larger population of interest). The cost of providing care and following a large number of subjects can be substantial. For many medical therapies, for example, new drugs, or new devices, the Food and Drug Administration (FDA) requires RCTs to document safety and efficacy prior to FDA approval for use and sale in the United States. In dentistry, this is somewhat less common due to the nature of many dental therapies. For example, over-the-counter products such as toothpaste and oral rinses do not need to go through an FDA-approved RCT process. Many surgical interventions, dental implants, and orthodontic devices are all exempt from FDA oversight. Manufacturers are often reluctant to incur the cost of establishing efficacy using a large RCT if they can market their products without such trials. Consequently, many of the approaches to treatment and many of the devices used in dentistry are lacking established efficacy as determined by an RCT.

The reasons for low external validity in RCTs are related to the nature of the subjects who can be successfully recruited into an RCT design. Oftentimes an individual who volunteers for a research study is substantially different (e.g., sicker or more compliant with therapy) than an individual in the community with the same condition who does not volunteer. Hence, it is often unclear if the findings from the RCT will be broadly applicable to individuals with the condition who were not included in the study.

As a result of the concerns over low external validity and safety, many RCTs represent only the initial assessment of therapeutic efficacy. Many drugs and devices continue to be followed once they are approved for the market through postmarket surveillance programs. These programs provide for reporting of unexpected outcomes and serve to identify rare side effects after the therapy is in broader use.

It should be noted that although RCTs are well suited for identifying the efficacy of a new therapy, they may not be a good estimate of effectiveness. Efficacy is the potential of a therapy to provide a benefit under “ideal” conditions. *Ideal* refers to the optimal selection of subjects and delivery of the therapy, conditions which are optimized in RCTs. Most RCTs have stringent inclusion and exclusion criteria that select for subjects most likely to benefit from the therapy. Additionally, the delivery of the therapy in regards to compliance or provider skill is also monitored to ensure optimal delivery. The low risk of bias and careful control of operational procedures contribute to the RCTs’ high internal validity.

Effectiveness is the ability of the therapy to provide a benefit under more “real world” conditions, as found in routine clinical practice. Once efficacy is established within the RCT, most therapies are then made widely available and enter routine practice. It is here where the delivery of the therapy may differ in substantial ways from those encountered in the RCT. For example, the stringent exclusion criteria found in the RCT may now be ignored, hence sicker patients or patients with comorbid conditions that alter the efficacy of the therapy may begin to receive it. Additionally, especially with surgical interventions (e.g., dental implants), provider skill may vary from that of the providers trained for the RCT. Consequently, benefits to patients may not approach the level found in the RCT. This difference can be substantial and should be understood by the clinician when considering therapeutic options and providing informed consent.

Quasi-Experiments

The other common experimental designs are known collectively as quasi-experimental designs. The main difference between these designs and RCTs is that the quasi-experimental designs lack a randomized control group. In fact, they often lack a separate control group altogether and rely on before and after designs with the same group. These designs are popular in the social and behavioral sciences but would not be adequate for new drug-or device-approval studies. A complete description of these designs is provided by Campbell and Stanley (1963).

Systematic Reviews and Meta-Analysis

Systematic reviews and meta-analytic studies represent the latest wave of innovations that are changing the way in which information is gathered, summarized and distributed for use by clinicians. In the early days of evidence-based medicine (and dentistry), which is

to say the 1990s, clinicians were taught how to review and evaluate individual studies so that they could conduct personal reviews of the literature and arrive at an informed approach to care. The skills needed to master the scientific literature were not trivial and required a considerable amount of effort to master. However, once mastered, they provided the clinician with the ability to sort through the mass of clinical literature, tease out those papers worth reading, and determine what information was valid and relevant enough to inform their clinical practice.

A major shortcoming of this approach was that the amount of clinical literature being produced, tens of thousands of articles each year, was so vast that any busy clinician could only hope to read a small portion of it. Consequently, much information inevitably would be missed, leading to a partial understanding of the status of current research on a given topic. Even worse, it could potentially create an information bias or confirmation bias if a clinician limited his or her reading only to research that conforms to the clinician's existing beliefs or practices.

Problems with the published literature are highlighted by this quote from The Cochrane Collaboration website (2010):

It is a difficult task for practitioners to keep up-to-date with the relevant evidence in their field of interest: the major bibliographic databases cover less than half the world's literature and are biased towards English-language publications; textbooks, editorials and reviews that have not been prepared systematically may be unreliable; much evidence is unpublished, but unpublished evidence may be important; and more easily accessible research reports tend to exaggerate the benefits of interventions.

The fact that there was useful information not being used by clinicians, either due to time constraints limiting their ability to search and read the literature or lack of knowledge about how to interpret studies, was brought to light by Archie Cochrane as far back as the 1970s. Cochrane noted that there was useful information being ignored by clinicians as well as the persistent use of therapies that were documented as being ineffective. Cochrane thought that this could be remedied by making high-quality information more easily available in a form that properly summarized the current knowledge on a topic in an unbiased and easily understood manner. He received funding from the British National Health Service to set up a program to develop and disseminate information to medical practitioners. The approach they used evolved into what is now known as systematic reviews and led to the establishment of the now well-known Cochrane Collaboration, the foremost creator and distributor of systematic reviews for medicine and dentistry in the world.

Features of a Systematic Review

A systematic review summarizes the results of available carefully designed health-care studies (usually controlled trials) and provides a high level of evidence on the effectiveness of health-care interventions.

The reviewers set about their task very methodically, following step by step an advance plan. The steps typically followed in conducting a systematic review are as follows:

- Create a rationale or statement of purpose based on a question about clinical practice.

- Conduct a search for evidence. This almost always includes computerized databases (e.g., Medline), but can also include hand searches of relevant journals, non-English-language journals, and the gray literature (e.g., nonpublished reports, theses, dissertations).
- Identify studies that meet basic inclusion criteria (Cochrane often limits included studies to RCTs.)
- Review these studies in detail for relevance.
- If the studies are not relevant, reject them.
- If the studies are relevant, evaluate their methodological quality.
- If quality is sufficient, extract data.
- Analyze the data in context with other studies.
- Summarize and draw conclusions.

When the underlying measurements used in RCTs are similar enough, it may be possible to mathematically combine the results of several studies to conduct a new analysis of the combined data. This is called a meta-analysis and is a means to improve the overall sample size and hence statistical power of the analysis. It also allows for an estimate of an overall effect that may better capture the real effect of a treatment or intervention.

For most clinicians, reading systematic reviews and meta-analyses is the preferred approach for answering a clinical question regarding patient care. Systematic reviews, when done using well-established and valid search criteria such as those employed by The Cochrane Collaboration, provide, in general, a much more exhaustive examination of the state of the current research. They also provide an objective selection of studies and data extraction processes. Consequently, they can quickly provide the reader with, arguably, the highest quality, least-biased evidence available on the efficacy, safety, and value of any given therapy and allow us to resist the influence of Glacow's law [which states "one half-baked observation I made personally is equal in validity to 12 randomized, double-blind trials." (Kunin 1979)]. Thus, systematic reviews are highly recommended as the first choice for evidence in support of clinical decision making. Dr. Jones would be well served in her quest to understand the benefits of early treatment by referring to the Cochrane Review that addresses this topic (Harrison, O'Brien, and Worthington 2009).

References

- Altman, D.G., Schulz, K.F., Moher, M. et al., 2001. The revised CONSORT statement for reporting randomized trials: explanation and elaboration. *Annals of Internal Medicine* 134, pp. 663–694.
- Bolton, W.A., 1958. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. *Angle Orthodontist* 28, pp. 113–130.
- Campbell, D.T. & Stanly, J.C., 1963. *Experimental and quasi-experimental designs for research*. Boston: Houghton Mifflin.
- Cochrane Collaboration, 2010. Home page. <http://www.cochrane.org/>.
- Cochrane, A.L., 1972. *Effectiveness and efficiency: Random Reflections on Health Services*. London: Nuffield Provincial Hospitals Trust.

- DeAngelis, C., 1990. *An introduction to clinical research*. New York: Oxford University Press.
- Harrison, J.E., O'Brien, K.D. & Worthington, H.V., 2007. Orthodontic treatment for prominent upper front teeth in children. *Cochrane Database of Systematic Reviews* 3, Art. No. CD003452, DOI 10.1002/14651858.CD003452.pub2.
- Hill, A.B., 1965. The environment and disease: association or causation? *Proceedings of the Royal Society of Medicine* 58, pp. 295–300.
- Kunin, C.M., 1979. *Practical aspects of antibiotic review*. Atlanta: American Health Consultants.
- Meinert, C.L., 1990. *Clinical trials: design, conduct, and analysis*. New York: Oxford University Press.
- Rothman, K.J. & Greenland, S., 1998. *Modern epidemiology*. 2nd ed., Philadelphia: Lippincott Raven.
- Randal, J., 1998. How randomized clinical trials came into their own. *Journal of the National Cancer Institute* 90, 1257–1258.
- Sackett, D.L., 1979. Bias in analytic research. *Journal of Chronic Diseases* 32, pp. 51–63.
- Salmon, M.H., Earman, J., Glymour, C. et al., 1992. *Introduction to the philosophy of science*. Indianapolis: Hackett Publishing Co.

3

Electronic Searching for Clinical Trials Information

Anne Littlewood, BA(Hons), MA, MCLIP

Trials Search Co-ordinator, Cochrane Oral Health Group, Manchester, UK

Introduction

The Cochrane Oral Health Group is part of The Cochrane Collaboration and comprises an international network of researchers involved in producing and disseminating systematic reviews of randomized controlled clinical trials in the field of oral health. Searching for trials information to include in systematic reviews is a complex process; in order to avoid bias in the results of the review as many relevant trials as possible must be found. There are many sources that can be searched, including MEDLINE and EMBASE (Excerpta Medica Database). However, these databases are growing month by month and advanced searching techniques are required to ensure that all relevant studies are found, but not at the cost of being overloaded by too many citations.

Searching electronic databases for systematic reviews requires a balance between sensitivity (number of relevant articles found as a proportion of all the relevant articles) and precision (the number of relevant articles found as a proportion of *all* articles). Searches for Cochrane systematic reviews attempt to aim for maximum sensitivity so that no relevant articles are missed. This chapter will cover which databases to search and how to construct a sensitive search strategy.

Where to Search: Choosing Databases

No one single resource covers all the information that is needed for a systematic review. A range of databases should be searched in order to make sure that all eligible trials are found and included. A search will normally cover the more mainstream medical databases, MEDLINE and EMBASE, and trials and systematic review information within The Cochrane Library as a minimum. Non-English language literature, gray literature, and trials registers are further sources of reports of clinical trials.

MEDLINE

MEDLINE is a resource from the United States, based at the National Library of Medicine. Records date back to 1949, and 5000 journals have been added to the resource. It currently contains over 16 million citations in 37 languages (National Library of Medicine 2008) and has a well-deserved reputation as the most comprehensive medical science database (Collins 2007). MEDLINE is available through several database providers, including Ovid and EBSCO, via a subscription. MEDLINE is also available for free online via the PubMed service at <http://www.ncbi.nlm.nih.gov/sites/entrez>.

EMBASE

EMBASE, the European equivalent of MEDLINE, is based in the Netherlands and produced by the publisher Elsevier. It has coverage of over 7000 journals since 1974 and has 20 million citations (Elsevier 2009). It has a particular focus on pharmacological sciences and also provides access to non-English language references. Like MEDLINE, it is available as a premium subscription service via several database providers including Ovid. The free online version of EMBASE is available at <http://www.embase.com/home>.

The Cochrane Library

The Cochrane Library, from Wiley Interscience, is produced by The Cochrane Collaboration. It contains several useful resources, which can be searched simultaneously. The Cochrane Database of Systematic Reviews contains all the published Cochrane reviews and protocols; at the time of writing there were nearly 6000 records covering all the subject areas of the Cochrane Review Groups (Wiley Interscience 2009). The Cochrane Central Register of Controlled Clinical Trials (CENTRAL) comprises the trials registers collated and maintained by the Cochrane Review Groups and currently contains over 600,000 clinical trials (Wiley Interscience 2009). In addition, The Cochrane Library includes access to the Database of Abstracts and Reviews (DARE) produced by the Centre for Reviews and Dissemination at the University of York, a specialized methodology register and collection of technology assessments and economic evaluations. Access to The Cochrane Library varies from country to country, but it is free to residents of many countries, including the following: the UK, Australia, Canada, Denmark, Finland, India, Ireland, some Latin American and Caribbean countries, New Zealand, Norway, Poland, Spain, and Sweden.

Access may also be available in other countries through individual or higher education library subscriptions.

The Cochrane Library can be accessed through The Cochrane Collaboration's website at <http://www.cochrane.org>.

Non-English Language Literature

MEDLINE, EMBASE and CENTRAL within The Cochrane Library all provide access to non-English language citations of clinical trials, but there are alternative sources of information. One of the largest non-English language databases is the Latin American and Caribbean Health Sciences Literature Resource (LILACS), which provides access to references from journals published in South and Central America. It can be searched in English, Spanish, or Portuguese. Access in the UK can be gained through the Virtual Health Library (<http://www.bireme.br>). There are country-specific databases with some limited trials information, such as KoreaMED (<http://www.koreamed.org>). Other non-English language sources include the Chinese biomedical databases provided through Infobank (<http://www.infobank.cn>) and the various databases provided through the World Health Organization (WHO). These include resources for the eastern Mediterranean (<http://www.emro.who.int/his/vhsl>), Southeast Asia (<http://library.searo.who.int/>), and Africa (<http://indexmedicus.afro.who.int>).

Trials Registers

Information about clinical trials, both ongoing and completed, can be found on trials registers. Cochrane Review Groups all maintain a specialized register of trials in their subject area. The Cochrane Oral Health Group's register currently contains approximately 25,000 references to published clinical trials information. Access to the Cochrane trials registers is normally arranged through the Review Group's Trials Search Coordinator (more information can be found on www.cochrane.org). Information on ongoing trials in the UK can be found on the Meta-Register of Controlled Clinical Trials (<http://www.controlled-trials.com/mrct/>), a resource that is free to search and that gives details regarding the study design, outcomes, and contact information. The U.S. National Institutes of Health provide free access to <http://clinicaltrials.gov>, a database containing over 80,000 trials records (NIH 2009). Its coverage aims to be global, but there is an inevitable concentration on trials from the United States. The information provided includes the trial's purpose, participants, and contact information. WHO provides a gateway to several trials registers at <http://www.who.int/trialsearch>. The registers covered include the Australia and New Zealand Clinical Trials Registry, the Chinese Clinical Trial Register, the Indian Clinical Trials Registry, the German Clinical Trials Register, the Iranian Registry of Clinical Trials, and the Netherlands Clinical Trials Register (WHO 2009). In addition to these trials registers, pharmaceutical companies also maintain registers of the clinical trials they have conducted. Many of these have been brought together by the International Federation of Pharmaceutical Manufacturers and Associations and published online via a gateway that is free to search at <http://clinicaltrials.ifpma.org>. This provides access to information such as trial sponsors, the condition and intervention being investigated, start and completion dates, and inclusion and exclusion criteria.

Gray Literature, Dissertations, and Conference Proceedings

Gray literature is that which is not formally published in books or journals. Along with dissertations and conference proceedings, it can be a useful source of trials information. OpenSIGLE (<http://opensigle.inist.fr/>) is the System for Information on Grey Literature in Europe and is a database of references relating to reports, dissertations, and conference papers. Although it ceased to be fully updated in 2005, it is still worth searching for older material. Access is free of charge. Conference proceedings can be found via a number of resources, including ZETOC (<http://zetoc.mimas.ac.uk>), the Web of Knowledge (<http://isiwebofknowledge.com>), and British Library Direct Plus (<http://tinyurl.com/a27pc8>). All of these are normally free to staff and students within UK higher education institutions, but they are also available via a subscription to those outside UK universities. Selected dissertation abstracts are also available online. Ethos (<http://ethos.bl.uk>) is a service provided by the British Library and has 250,000 records of abstracts of dissertations from UK universities. Database provider ProQuest also provides a dissertation and thesis service, although this is available by subscription only.

Choosing the Right Platform

Many of the resources listed above are available via several different service providers: platforms that offer access to these electronic databases include Ovid, EBSCO, PubMed, EMBASE.com, and SilverPlatter. Some of these require a subscription to access, some (PubMed, EMBASE.com) are free of charge. The subscription services are normally superior in that they allow more sophisticated and advanced searching and sometimes provide links to the full text of the citation. In most cases where there is access to both, the subscription services should be used in preference to the free versions. Most university and medical libraries subscribe to at least one of the subscription services, and advice should be sought from a subject specialist or librarian as to which are available and how to access them. Search syntax and subject headings vary from platform to platform, so it is important to know how the database is being accessed so that the search can be tailored appropriately. A search designed for MEDLINE via Ovid will not work in MEDLINE via PubMed. All of the mainstream medical databases provide help on their websites to assist in a correct and structured search strategy.

How to Search: Constructing a Search Strategy

Electronic Records

Most of the electronic databases mentioned above provide access to citations from journals, not the full text of the article. Some also contain access to citations from books, conference proceedings, and dissertations. Electronic records normally contain basic information about an article such as authors, title, journal, volume and issue, page numbers, language, and year of publication. In most cases, more detailed information can also be found, such as an abstract and contact details for the authors, although some older articles may have been added without abstracts. Many of the databases above also index all the journal articles with keywords and controlled vocabulary to help in searching.

Controlled Vocabulary

Most of the mainstream medical literature databases can be searched using a mixture of controlled vocabulary and free text. Controlled vocabulary is a list of words and phrases used to “tag” information in electronic databases in order to group similar articles together. The most famous example in this context is MEDLINE’s Medical Subject Headings (MeSH). MeSH terms are arranged in a hierarchy, or tree. Broader concepts come near the top of the tree and more specific terms lower down.

These subject headings are then assigned to the articles in MEDLINE by experienced indexers at the National Library of Medicine (NLM) in the United States. MeSH can be found for a topic by visiting the NLM’s MeSH browser at <http://www.nlm.nih.gov/mesh/MBrowser.html>. Typing in a keyword will not only give the MeSH term for that topic, but it will also show where the term appears in the MeSH tree. The MeSH term can be used in MEDLINE to search for any records that have been indexed with it.

MeSH can also be “exploded” to include all of the terms that are included in that subject heading on the tree. For example, exploding the term “Orthodontic Appliances, Removable” (Table 3.1), would also search the terms “Activator Appliances” and “Extraoral Traction Appliances.” However, you can also focus your search by not exploding the term. An unexploded search for “Orthodontic Appliances, Removable” would only retrieve the records indexed with that term and not the records indexed with “Activator Appliances” and “Extraoral Traction Appliances.”

Controlled vocabulary is used not only in MEDLINE but in other electronic databases also, including EMBASE and The Cochrane Library. However, the terms used do vary from database to database, so the subject headings may have to be translated to make the search work in electronic resources other than MEDLINE.

Free-Text Searching

Searching for MeSH terms or controlled vocabulary limits the search to include only those terms that appear in the keyword field of a record, whereas free-text searching can be

Table 3.1 Example of a MeSH tree on orthodontic appliances.

Orthodontic Appliances
Occlusal Splints
Orthodontic Appliances, Functional
Activator Appliances
Orthodontic Appliances, Removable
Activator Appliances
Extraoral Traction Appliances
Orthodontic Brackets
Orthodontic Retainers
Orthodontic Wires

Source: National Library of Medicine, Medical Subject Headings.

applied in any field in the record: author, abstract, keywords, or even full text. Most electronic databases support the search of single words or phrases, such as “orthodontic appliances.” Searchers should avoid, however, just using free-text at the expense of controlled vocabulary. If free-text alone is used, the search will be limited to just those words or phrases you have entered. For example, a search for “jaw abnormalities” as free-text will search for only that phrase where it appears in the title, abstract, or keyword fields. However, the same phrase exploded as a MeSH term will also pick up those records indexed with further terms, including cleft palate, retrognathism, and Pierre Robin syndrome, records that the free-text search for “jaw abnormalities” would miss. However, MeSH indexing is not always fully comprehensive either, especially for older or foreign language records. Ideally, a full search should contain a combination of controlled vocabulary and free-text to ensure that all bases are covered.

Boolean Operators

One or more terms can be combined in a search using Boolean operators: these are supported by most electronic databases. The most common operators are AND, OR, and NOT. AND is used when the records retrieved from the search must contain all of the search terms. The OR command is used when the records retrieved in the search can contain either of the search terms whether or not they appear together in the record. The NOT command is for searches in which one term can be retrieved but the other must not be, even if it appears alongside the included term.

To put this into context, if you were searching for a study on orthodontic treatment for crowded teeth, a search for “orthodontic appliances” AND “crowded teeth” would usefully combine both terms to retrieve only the articles that contain both phrases.

However, not all articles may include the term “crowded teeth,” and this is where the OR command is used to join synonyms together. For example, “crowded teeth” OR “Class I malocclusion” OR “Class II malocclusion” would pick up all of the articles containing any of these phrases in a free-text search.

The basic rule with Boolean operators is that AND will decrease the number of records retrieved in a search, where OR tends to increase the number of hits. Boolean operators

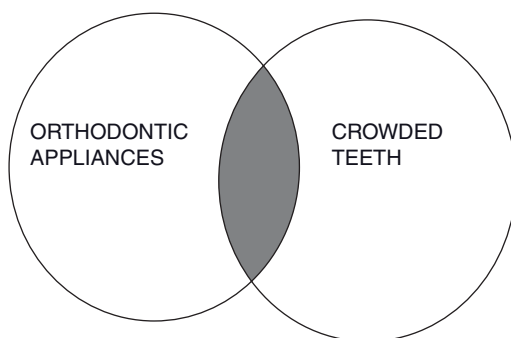


Figure 3.1 The AND command, “orthodontic appliances” AND “crowded teeth,” will only retrieve articles containing both terms (the shaded area).

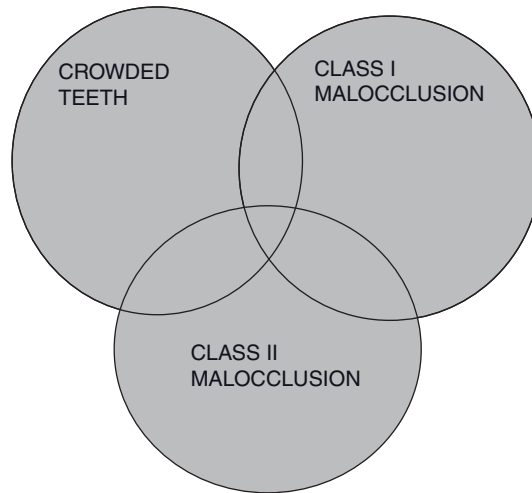


Figure 3.2 The OR command, “crowded teeth” OR “Class I malocclusion” OR “Class II malocclusion,” will retrieve all articles with these terms, whether they appear together in the article or not. This is useful for finding synonyms.

can be combined together with brackets. A search for (“crowded teeth” OR “Class II malocclusion”) AND (“orthodontics”) would search for all instances where the two phrases for the condition in question are discussed in the same article as orthodontics.

The Boolean NOT command should be used with caution, especially in the context of systematic reviews. Searches should be designed to be as sensitive as possible in order to make sure every clinical trial on a subject is retrieved. The NOT command is designed to exclude articles from a search thus is rarely used in the construction of a search strategy for systematic reviewing. Use of the NOT command can also risk excluding articles that may be relevant. A search for “cancer NOT children” is designed to retrieve all articles about cancer but not cancer in children. However, if the abstract included the sentence “The participants in the trial were women with cervical cancer who had been pregnant and had children,” then a search for “cancer NOT children” would not pick up this potentially relevant paper.

Truncation and Wildcards

All of the mainstream databases discussed here support truncation, which enables searching on the “stem” of a word, a technique that is useful when searching for words that could be pluralized. For example, a search for “child*” on PubMed would retrieve all articles containing the terms “child” or “child’s” or “children.” This saves time, as the search does not then have to include all variations on a word. Some databases will also support wildcard searches, where a letter within a word can be replaced with a symbol so that the database search tool looks for all variations of a word. Within MEDLINE on the Ovid platform, the “?” symbol can be used as a wildcard. For example, “wom?n” will retrieve

articles containing the terms “women” and “woman” and “remineralization” would retrieve “remineralisation” and “remineralization.” Symbols for truncation and wildcards vary from database to database, so the Help or Frequently Asked Questions sections of websites should be checked to ensure the correct symbol is being used. The symbols *, \$, %, and ? are all commonly used for truncation or as wildcards.

Proximity Operators

Some databases allow the searching of terms that are in close proximity to one another. This is a more precise method of searching than using AND but is also more flexible than using a phrase search. A search for “dental anxiety” as a phrase would search for only those articles where the words appear next to each other. Searching “dental AND anxiety” would search for either term anywhere in the article. However, if a search for “dental near/6 anxiety” is conducted in The Cochrane Library, any references where the term “dental” is found within 6 words of the term “anxiety” will be retrieved. This can be a useful tool if you have many irrelevant results from an AND search and want to cut them down to a more relevant subset.

Not all database platforms support proximity searching. Most notably, PubMed does not, which is one of its limitations. As with truncation, the terminology for proximity searching varies from database to database. Ovid databases use “adj” for adjacent to, and EBSCO databases use the letter *N*. Again, the Help pages of each individual database should be checked to see if proximity searching is available and what the correct terminology is.

Building a Search Strategy

The first step in constructing an electronic search strategy is to identify relevant search terms or groups of terms that can be used as the basis of the strategy. It may be helpful at this stage to think in terms of participants or target population, the intervention of interest, and the condition of interest. For example, the systematic review entitled “Orthognathic surgery for the correction of mandibular deficiency in adults” can be broken down as seen in Table 3.2.

These kinds of section headings can help to provide a framework for the search. To date, bibliographic databases (unlike many search engines) are not especially intuitive and will search only for the terms that are entered. It is therefore important to find as many synonyms as possible for each of these section headings.

If we take the example above, synonyms and related terms for orthognathic surgical treatments or interventions could include

- bilateral sagittal split osteotomy,
- distraction osteogenesis,
- genioplasty,
- mandibular advancement surgery, and
- chin surgery.

Table 3.2 Identifying elements of the search question.

Participants/population:	Adults
Intervention/treatment:	Orthognathic surgery
Condition of interest:	Mandibular deficiencies

Synonyms for the condition of interest in this case could include

- jaw abnormalities,
- mandibular deformities,
- retrognathism,
- dentoskeletal deformities, and
- mandibular hypoplasia.

Participants are more difficult to add to a search. The term “adults” added to this search, for example, would not necessarily retrieve more studies, as the term “adult” may not be mentioned in all the studies on the topic. Participants could simply be called “patients” or “subjects,” terms that may also include children! Participant information is better added to a search if you have a specific group of people or patients that are pertinent to the study, for example, smokers or infants. In this example, the most essential sections to search for are terms for the intervention and condition, to make the search as sensitive as possible.

All of the synonyms identified for (in this example) the condition and the intervention should be listed. The NLM’s MeSH browser should now be checked to see if any of the identified terms have a Medical Subject Heading (<http://www.nlm.nih.gov/mesh/MBrowser.html>). It is also worth checking where on the MeSH tree a term appears to see whether any the subject headings above the identified term could be exploded to make the search more comprehensive. There may also be other synonyms in the MeSH tree that could be added to the search as free-text terms.

For the example above, the following MeSH terms were identified.

Condition

- Jaw abnormalities: Exploded, this term would include other subject headings, including cleft palate, Pierre Robin syndrome, and prognathism. Not all of these are relevant to this search, which concentrates on mandibular deformities, so the term should not be exploded.
- Retrognathism: This is a subject heading on the MeSH tree, which could be relevant.

Intervention

- Mandibular advancement: This is the last heading on the tree and so would not need to be exploded.

Once the MeSH terms have been identified, the next stage is to start to build the free-text search. Taking the list of identified synonyms, the following questions need to be asked:

- Can any of the terms be truncated?
- Are there any alternative spellings?
- Are there any hyphens in any of the terms?

Hyphens can be problematic because the term could appear either with or without it in the literature. For example, “bite-plate” could also appear as “bite plate.” Both versions should appear in the search strategy.

The search strategy for the condition can now be built. The example used here is for PubMed and has been adapted from an Ovid search in a Cochrane Protocol (Khader et al. 2009). The first two lines are MeSH terms, and the rest of the search is presented in free-text. The square brackets after the terms are field tags, which indicate to PubMed which part of the record to search. The field tag [mh] represents the MeSH term, which can be exploded, [mh:exp], or not exploded, [mh:noexp]. A full list of field tags can be found on the NLM website (<http://tinyurl.com/n2td6a>).

- #1 Jaw Abnormalities [mh:noexp]
- #2 Retrognathism [mh:noexp]
- #3 ((mandibular and deformit*) or (mandible and deformit*))
- #4 ((mandibular and deficien*) or (mandible and deficien*))
- #5 ((mandibular and retrognat*) or (mandible and retrognat*))
- #6 (dentoskeletal and deformit*)
- #7 ((hypoplas* and mandible) or (hypoplas* and mandibular))

These are the identified terms for the condition and the identified MeSH terms. Some have been truncated to pick up the plurals. Terms have been combined using and/or. Line #8 of the strategy should now combine all of these terms to tell PubMed that any or all of them could appear in the retrieved results.

- #8 #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7

This completes the search for the condition. Terms for the intervention should now be added to the search:

- #9 Mandibular advancement [mh:noexp]
- #10 (orthognathic and (surgery or surgical*))
- #11 (“bilateral sagittal split osteotom*” or “bi-lateral sagittal split osteotom*”)
- #12 (“distraction osteogenesis”)
- #13 genioplast*
- #14 ((#9 or “mandibular advancement” or chin) AND (surgery or surgical))
- #15 #9 OR #10 OR #11 OR #12 OR #13 OR #14

The final line of the strategy should bring together the condition and the intervention by using the AND command. This tells PubMed that you want only records about mandibular deformity that are also about orthognathic surgery. The next line in this example should be

#16 #8 AND #15

Once the search strategy has been completed by combining the two sets of terms, the search should be tested in PubMed using the advanced search.

Questions to ask here are the following:

- Are the numbers of hits retrieved manageable? (Generally less than 1000.)
- Are any lines retrieving no hits? It may be that the wrong MeSH term has been used or that one of the terms has been spelled or truncated incorrectly.
- Have any relevant keywords been missed?

Revisions should be made at this stage. If the number of hits is unmanageable, it may be possible to reduce the number by using proximity operators instead of AND, depending on the platform. This is not possible in PubMed. Another way to cut down the number of hits is to use a search filter.

Search Filters

Search filters are normally used to limit the search to particular study designs, for example, if the searcher is only interested in randomized trials or systematic reviews. They are designed to make the search more precise. There are standardized search filters available for use, and the InterTASC group is starting to put together a web resource reviewing their efficacy. The website has filters for diagnostic tests, clinical trials, adverse events studies, economic evaluations, and qualitative research, among others (<http://www.york.ac.uk/inst/crd/intertasc/>).

Many of these have been peer reviewed by information specialists.

An example would be the search filter that The Cochrane Collaboration has developed for finding randomized controlled trials in MEDLINE (Glanville et al. 2006). This filter has been tested against a gold standard of known records of randomized controlled trials within MEDLINE. The filter for PubMed has been published in *The Cochrane Handbook of Systematic Reviews for Interventions* (in the handbook's box 6.4a) (Lefebvre, Manheimer & Glanville 2009).

#1 randomized controlled trial [pt]

#2 controlled clinical trial [pt]

#3 randomized [tiab]

#4 placebo [tiab]

#5 drug therapy [sh]

#6 randomly [tiab]

#7 trial [tiab]

#8 groups [tiab]

#9 #1 or #2 or #3 or #4 or #5 or #6 or #7 or #8

#10 animals [mh] NOT humans [mh]

#11 #9 not #10

Search filters can be added to a search by taking the last line of the subject search and the last line of the search filter and adding an AND command, as in the example below:

```
#1 Jaw Abnormalities [mh:noexp]
#2 Retrognathism [mh:noexp]
#3 ((mandibular and deformit*) or (mandible and deformit*))
#4 ((mandibular and deficien*) or (mandible and deficien*))
#5 ((mandibular and retrognat*) or (mandible and retrognat*))
#6 (dentoskeletal and deformit*)
#7 ((hypoplas* and mandible) or (hypoplas* and mandibular))
#8 #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7
#9 Mandibular advancement [mh:noexp]
#10 (orthognathic and (surgery or surgical*))
#11 ("bilateral sagittal split osteotom*" or "bi-lateral sagittal split osteotom*")
#12 ("distraction osteogenesis")
#13 genioplast*
#14 ((#9 or "mandibular advancement" or chin) AND (surgery or surgical))
#15 #9 OR #10 OR #11 OR #12 OR #13 OR #14
#16 #8 AND #15
#17 randomized controlled trial [pt]
#18 controlled clinical trial [pt]
#19 randomized [tiab]
#20 placebo [tiab]
#21 drug therapy [sh]
#22 randomly [tiab]
#23 trial [tiab]
#24 groups [tiab]
#25 #17 or #18 or #19 or #20 or #21 or #22 or #23 or #24
#26 animals [mh] NOT humans [mh]
#27 #25 not #26
#28 #16 AND #27
```

This will limit the search for studies on orthognathic surgery for mandibular deficiencies to controlled trials.

Translating the Strategy

Once the MEDLINE strategy has been perfected, it needs to be translated for use in other databases. The golden rule is to check the help or frequently asked questions sections of the database website to ensure that the correct symbols are used to truncate and that the correct terms are used in terms of controlled vocabulary. Controlled vocabulary varies from database to database, and MeSH terms are revised once a year, so should be checked whenever the search is updated. The field tags and search terminology should also be checked; for example, is there another way of searching the title or abstract fields? If a line in your search retrieves fewer hits than expected, then it may need to be revised. Building a good search strategy is a process of trial and error, and all searches should be tested and revised accordingly.

Summary

- A range of sources should be searched to find eligible trials for a systematic review. These should include MEDLINE, EMBASE, and The Cochrane Library as a minimum.
- The method or platform for accessing the database is important, as a search designed for one platform will not necessarily work in another. PubMed and EMBASE.com are free to search, but the subscription services usually offer more advanced searching and should be used if available. Advice on access should be sought from a specialist medical librarian.
- A sensitive search strategy will be a mix of controlled vocabulary (such as MeSH terms) and free-text or keywords.
- Free-text can be truncated, and many database platforms support wildcard and proximity searching.
- Search terms can be combined using Boolean operators: AND, OR, and NOT. AND will decrease the number of hits, and OR will increase the number of hits. NOT should be used with caution.
- Search filters can be added to limit the search to particular study designs such as systematic reviews or randomized controlled trials.
- The creation of a search strategy is a trial-and-error process, and all searches should be tested. The Help or Frequently Asked Questions pages of the electronic database should be checked for tips on how to structure the search.

Useful Resources

- British Library Direct Plus (Conference proceedings). Available at: <http://tinyurl.com/a27pc8>
- Chinese Infobank. Available at: <http://www.infobank.cn> [in Chinese]

- Clinical Trials.gov. Available at: <http://clinicaltrials.gov>
- *The Cochrane Handbook* (chapter 6). Available at: <http://www.cochrane-handbook.org>
- The Cochrane Library. Online via The Cochrane Collaboration website. Available at: <http://www.cochrane.org/>
- The Cochrane Oral Health Group. Available at: <http://www.ohg.cochrane.org/>
- Electronic Theses Online Service (ETHOS). Available at: <http://ethos.bl.uk>
- EMBASE. Available at: <http://www.embase.com>
- International Trials Registry Platform. Available at: <http://apps.who.int/trialsearch/>
- InterTASC Search Filters Resource. Available at: <http://www.york.ac.uk/inst/crd/intertasc/>
- KoreaMED. Available at: <http://www.koreamed.org>
- Latin American and Caribbean Health Sciences Literature Resource (LILACS). Available at: <http://www.bireme.br>
- MEDLINE via PubMed. Available at: <http://www.ncbi.nlm.nih.gov/sites/entrez>
- Meta-Register of Controlled Clinical Trials. Available at: <http://www.controlled-trials.com/mrct/>
- National Library of Medicine MeSH Browser. Available at: <http://www.nlm.nih.gov/mesh/MBrowser.html>
- Open System for Information on Grey Literature in Europe (OpenSIGLE). Available at: <http://opensigle.inist.fr/>
- Web of Knowledge. Available at: <http://isiwebofknowledge.com>
- World Health Organization Gateway. Available at: <http://www.who.int/>
- ZETOC (Conference proceedings). Available at: <http://zetoc.mimas.ac.uk>

References

- Collins, J., 2007. Evidence-based medicine, *Journal of the American College of Radiology* 4, pp. 551–554.
- Elsevier B.V., 2009. *Embase Biomedical Answers* [Online]. Available at: <http://www.info.embase.com/what-is-embase> [Accessed on October 29, 2009].
- Glanville, J., Lefebvre C., Miles, J.N. et al., 2006. How to identify randomized controlled trials in MEDLINE: ten years on. *Journal of the Medical Library Association* 94, pp. 130–136.
- Khader, N., Cobourne, M., Sherriff, M. et al., 2009. Orthognathic surgery for surgical correction of patients with mandibular deficiency (protocol). *Cochrane Database of Systematic Reviews* 3, Art. No., CD007860. DOI 10.1002/14651858.CD007860.
- Lefebvre, C., Manheimer, E. & Glanville, J., 2009. Searching for studies. In: J.P.T. Higgins & S. Green, eds. *Cochrane handbook for systematic reviews of interventions*. 5.0.2 ed. Chapter 6

- (updated September 2009). *The Cochrane Collaboration* [Online] Available at: <http://www.cochrane-handbook.org> [Accessed on October 29, 2009].
- National Library of Medicine, 2008. *MEDLINE Fact Sheet* [Online] Available at: <http://www.nlm.nih.gov/pubs/factsheets/medline.html> [Accessed October 29, 2009].
- U.S. National Institutes of Health (NIH), 2009. *Clinical trials.gov* [Online] Available at: <http://www.clinicaltrials.gov> [Accessed on October 29, 2009].
- Wiley Interscience, 2009. *About The Cochrane Library* [Online] Available at: <http://tinyurl.com/ykkyxus> [Accessed on October 29, 2009].
- World Health Organization, 2009. *International clinical trials registry platform search portal* [Online] Available at: <http://apps.who.int/trialsearch/> [Accessed on October 29, 2009].

Part 2

Selected Topics

The Treatment of Class II Malocclusion—Have We the Evidence to Make Decisions?

Kevin O'Brien¹, BDS, FDS, DOrth RCS, PhD,
Jonathan Sandler², BDS (Hons), MSc, FDSRCPS, MOrth RCS

¹Professor of Orthodontics, School of Dentistry, University of Manchester, Manchester, UK

²Consultant Orthodontist, Chesterfield Royal Hospital, Chesterfield, UK

We will outline the evidence base for the treatment of children with Class II malocclusion by confining our sources to randomized trials and systematic reviews. We will base the chapter around common clinical dilemmas that are faced by all orthodontists on a daily basis.

These are as follows:

1. Should we provide treatment when the child is in the early transitional dentition as a phase I treatment with a functional appliance or headgear, followed by a phase II course of treatment when the child is an adolescent?
2. If a decision is made to wait until the child is in adolescence, should we provide treatment with a functional appliance or headgear to attempt to modify the growth or alternatively carry out treatment to correct the overjet using fixed appliances?
3. Should we carry out a treatment at all in adolescence compensating for skeletal discrepancies or perhaps wait until the child's jaw growth is almost complete and then provide orthognathic surgical treatment?

Over the last 10 years, there have been several high level trials and systematic reviews that have provided us with a substantial amount of information on the evidence base for the treatment of Class II malocclusion. It is also important to point out that these studies have largely defined the patients according to their overjet. As a result, it may be more appropriate to consider that this discussion is primarily focused on the treatment of children with increased overjets. This then removes the need to discuss the perennial argument that Class II malocclusion cannot be readily categorized and treated by a “cookbook” approach that has its origins in clinical trials (Trenouth 2009; Hayes 2009).

Obtaining Research Evidence for Treating Increased Overjets in Class II Malocclusions

One of the most important publications in the treatment of increased overjets associated with Class II malocclusion was published over 20 years ago in 1990 (Tulloch et al. 1990). This paper did not change clinical practice overnight; however, it certainly inspired many orthodontic researchers to study treatment using randomized controlled trial (RCT) methodology and therefore is worth considering as an extremely valuable source of information. It was one of the first systematic reviews of the orthodontic literature, and the authors aimed to not only review the quality of the literature but also to answer the question on whether “methodological considerations—including sampling procedures, selection of comparison groups, choice of research design, consideration of confounding variables and statistical methods—might suggest that conclusions either supporting or refuting the growth modification effect of functional appliances should be regarded with caution.” The authors systematically reviewed the literature from 1980 to 1987 that had been published in the *American Journal of Orthodontics*, *Angle Orthodontist*, *The British Journal of Orthodontics*, and the *European Journal of Orthodontics*. They evaluated four main groups of variables that described the features of each study. These were (1) the type of appliance, (2) the research design, (3) the treatment setting and provider, and (4) the nature of the statistical analysis. They identified 50 studies, and it was clear that the most commonly used study design was retrospective (74%) compared with only 22% that were prospective. They also identified numerous problems with the treatment setting, data analysis, lack of sample size calculations, and selection bias.

It is worth quoting their final conclusion:

Given the problems of the multiple and limited indices of growth used by orthodontists—coupled with the weak research designs most frequently employed, the small sample sizes studied, and the ambiguous and incomplete reporting of important information—it is difficult to endorse conclusions supporting or refuting the growth-promoting influence of orthodontic appliances. Even the best of these studies suffer from methodologic limitations that make the interpretations of the results difficult. This review suggests that increased consideration of design, analysis and reporting would strengthen the value of clinical studies and permit more ready access to important information.

In short, the quality of evidence that underpinned the treatment of Class II malocclusion at that time was neither sufficient to confirm validity of, nor to lead to a change in,

clinical practice. This realization, in many ways, inspired investigators to attempt to improve the quality of research in orthodontics and more specifically into the treatment of increased overjets or Class II malocclusion. There are, however, considerable ethical issues associated with this type of research.

Ethical Issues in Class II Research

It is essential when investigators are planning a randomized trial that they are in a “position of equipoise” as to the effects of the interventions that they are hoping to assess in their study. It is clear that investigators have addressed these issues well in studies that have evaluated the effect of early orthodontic treatment provided to children aged 8 to 10 years old. This is because there are no ethical dilemmas randomizing this age group of patients to either early treatment, when they are in the transitional dentition (i.e., two phase), or to delayed treatment that is provided as one phase in adolescence.

However, when we consider that perhaps the most important question in Class II research is How much growth modification occurs as a result of this functional or headgear treatment in adolescence? It is therefore difficult to ethically design a study that would involve randomizing half the patients to an untreated control group. Consequently, most studies have been confined to an evaluation of the effectiveness of early treatment compared to later treatment or comparisons between two types of appliances on groups of age-matched patients. Nevertheless, these studies have revealed a sufficient amount information that helps us answer the dilemma that we are faced with when we consider the treatment of a child with an increased overjet.

Early Orthodontic Treatment for Class II Malocclusion

Over the last 20 years, the provision of treatment when children are 8–10 years old with the aim of “intercepting” a developing Class II malocclusion has become popular. Treatment involves intervention when the child is in the early mixed dentition (phase I) followed by a second course of treatment when they are in early adolescence (phase II). The proponents of this type of treatment suggest that this early intervention normalizes the skeletal pattern, reduces the length of any subsequent phase II treatment, or at least makes further treatment simpler by reducing the need for extractions. These claims have been tested in several randomized trials that have evaluated the effectiveness of early orthodontic treatment (Courtney et al. 1996; Dolce et al. 2007; O’Brien et al. 2003a; O’Brien et al. 2003b; O’Brien et al. 2009; Tulloch et al. 2004; Wheeler et al. 2002). The findings have also been incorporated into a systematic review of Class II treatment (Harrison et al. 2007), and we shall now consider the findings of this review, which has been published by The Cochrane Collaboration. This review was carried out according to Cochrane guidelines and summarizes the current state of knowledge. The authors systematically searched the literature confining the search to randomized and controlled trials that evaluated treatment to correct prominent incisors in children who were under the age of 16 years old. They were specifically interested in the outcome measures of incisor overjet, skeletal relationship, self-esteem, and any possible harms as a result of treatment. They searched

electronic databases and carried out a hand search, including trials that were not in the English language. They also carried out a quality assessment of each of the trials that were identified.

The electronic searches identified 185 studies, from which they obtained 105 full reports. After exclusions, they identified four trials concerned with early treatment for children aged 8–10 years old and four that evaluated the effects of treatment of children who were 10–15 years old. One problem that they identified was that there were multiple publications for three of the trials. They classified the trials according to their setting as follows: Florida, North Carolina, New Zealand, and UK.

All four studies were concerned with a comparison of active early treatment with an untreated control group. The Florida, North Carolina, and the UK study all followed the patients through to the conclusion of all orthodontic treatment; however, the New Zealand study only followed the patients to the conclusion of phase I. The *Cochrane Review* reported a meta-analysis that was carried out at the end of phase I and at the end of phase II.

The four studies all used slightly different treatment protocols for phase I treatment. The UK group used a Twin Block as the active intervention; the New Zealand group used a Frankel or a Harvold appliance; Florida evaluated two interventions, cervical pull headgear/biteplane combination and a bionator; and the North Carolina group evaluated cervical pull headgear and Bionator. All studies enrolled an untreated control group.

The results of these four high-quality studies are very similar and clinically important. When we consider the effect of early treatment compared to untreated controls, it appears that when a functional appliance was used, there was a modest difference in skeletal pattern (1.3 degrees), with a marked difference in incisor prominence (–4.0 mm). Similarly, the use of headgear resulted in small differences in ANB (–0.72 degrees) and overjet (–1.0 mm). The UK-based study also showed an increase in self-esteem for the treatment group. These trials were published at the end of the first phase of treatment, and although they were interesting, it could be suggested that the most important outcomes of this research were at the conclusion of all treatment when the child was an adolescent.

Three of the trials were extended to follow the patients through to the conclusion of orthodontic treatment, and the findings were included in the review (Harrison et al. 2007). A meta-analysis was carried out for final overjet, skeletal pattern, occlusal alignment (Peer Assessment Rating), incisal trauma, and self-esteem (O'Brien et al. 2009; Tulloch et al. 2004; Wheeler et al. 2002). The results of this analysis in the form of forest plots are shown for the effects of early treatment with a functional appliance versus one-phase treatment for final overjet, skeletal pattern (ANB), and occlusal alignment (PAR) in Figures 4.1–4.3. They concluded that

all the treatment was effective, in that incisor prominence had been reduced. Nevertheless, there were no differences in treatment outcome between the groups of children who had received one or two phases of treatment. As a result, it appears that two-phase treatment does not have any advantages over one phase treatment.

This is a compelling conclusion derived from a high level of scientific evidence and really suggests that early treatment does not confer any advantages of treatment that is provided in one phase during adolescence, apart from a transient increase in self-esteem.

Review: Orthodontic treatment for prominent upper front teeth in children

Comparison: 4 Early treatment at the end of Phase II: functional versus control

Outcome: 1 Final overjet

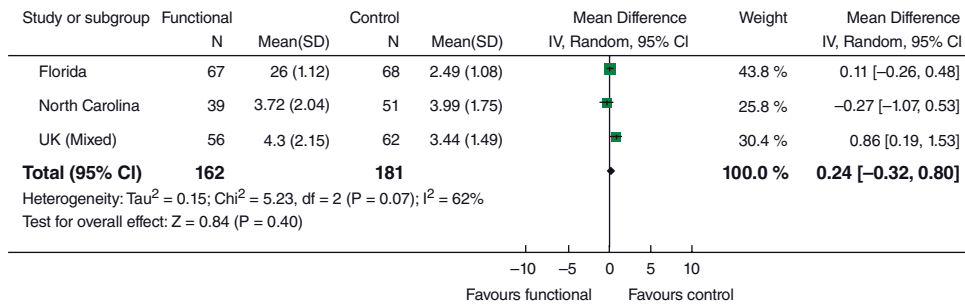


Figure 4.1 The effect of early treatment on overjet at the end of phase 2: functional appliance versus control (Harrison et al. 2007). Reprinted with permission.

Review: Orthodontic treatment for prominent upper front teeth in children

Comparison: 4 Early treatment at the end of Phase II: functional versus control

Outcome: 2 Final ANB

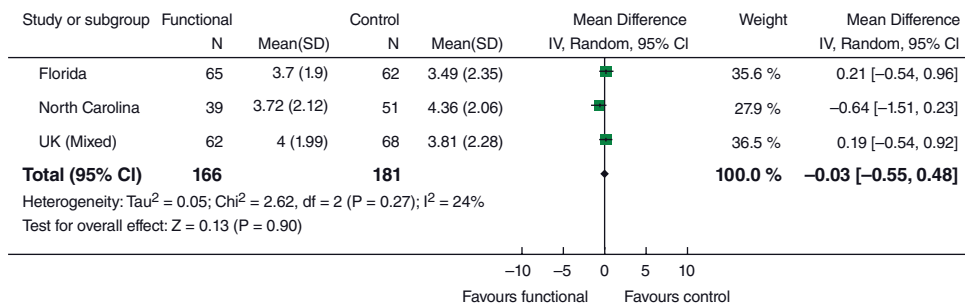


Figure 4.2 The effect of early treatment on final ANB at the end of phase II: functional versus control (Harrison et al. 2007). Reprinted with permission.

Stability of Treatment

There has been very limited prospective research on the stability of treatment, and the only quality publication is one of the final reports of the early treatment trial carried out in Florida (Pavlow et al. 2008). This paper reported on the stability of the occlusions for 208 subjects who completed phase II treatment using the Peer Assessment Rating (PAR) as an outcome measure (Richmond et al. 1992). They collected records on 173 (83%) who had at least one follow-up visit, with a median follow up of 5 years. The analysis of this dataset was complex due to several different retention methods and the time periods of follow-up. They concluded that the final PAR index scores were influenced by the PAR score at the end of treatment, years in retention, and PAR score at the start of phase II treatment. This suggested that patients who have early phase I treatment might have more

Review: Orthodontic treatment for prominent upper front teeth in children
Comparison: 4 Early treatment at the end of Phase II: functional versus control
Outcome: 3 PAR score

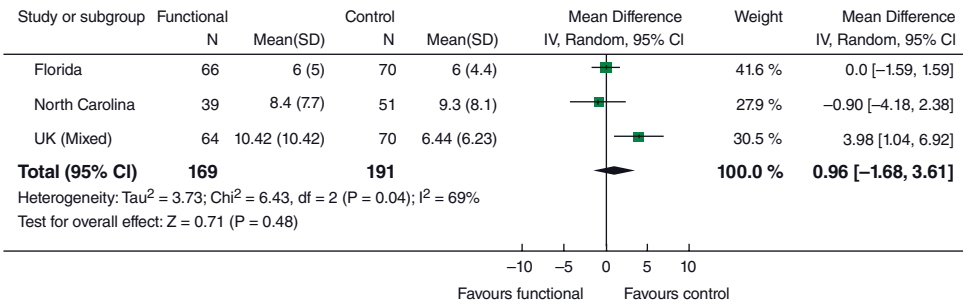


Figure 4.3 The effect of early treatment on PAR score at the end of phase II: functional versus control, outcome 3 PAR score (Harrison et al. 2007). Reprinted with permission.

stable post-treatment occlusions; however, the magnitude of this differences was not likely to be clinically significant according to the authors. Interestingly, they did not find any other predictors of relapse.

These findings are clearly the highest level of evidence regarding the effectiveness of early treatment for increased overjets. While the conclusions have been readily accepted, it is not clear if any influential authorities have changed their clinical guidelines for early treatment.

In the UK, our approach has not fundamentally changed, in that there is not really a great deal of early treatment being undertaken unless it is specifically indicated. Unless a child is being teased at school about his or her prominent teeth or his or her parents are unduly concerned about the prominence, then the advice would generally be to wait until the appropriate time where the overjet can reduced and there can be a seamless transition into full fixed appliances to enable the whole treatment to be completed within a 24-month period.

Treatment Provided During Adolescence

When treatment is provided in one phase, the orthodontist has several choices for whether they treat with a functional appliance, headgear, or fixed appliances only (or any combination of the three methods). This area has been researched fairly extensively, and while there have been some RCTs and systematic reviews for functional appliances, there is more limited research on headgear and fixed appliance combinations.

Functional Appliance Treatment

Treatment Carried out in One Phase in Adolescence with Functional Appliances

The question of whether to carry out treatment in one phase in adolescence was the subject of the review again by (Harrison et al. 2007). They identified four studies that evaluated

one-phase adolescent treatment: these were a series of trials carried out at the Royal London Hospital (Illing et al. 1998; Morris et al. 1998); a large multicentre trial comparing the effects of the Twin Block and the Herbst appliance (O'Brien et al. 2003c); and two earlier studies that had not received wide recognition. One of these investigated the effectiveness of the Bass appliance against an untreated control group (Cura & Sarac 1997); the other was a short paper by (Mao & Zhao 1997) in which they compared a Bionator/Headgear combination with an untreated control. These studies were interesting because they compared treatment against no treatment control in an adolescent group. We are not entirely certain how the ethical issues can be easily addressed apart from stating that treatment was delayed. There were some concerns with the quality of two of these studies. For example, Cura and Sarac (1997) did not clearly provide information on the patients who were lost to the study; they did not carry out an intention to treat analysis; and it was unclear how they actually concealed the allocation of treatment/control. In the study by Mao and Zhao (1997), it was not clear how allocation was concealed and whether data collection was blinded.

One of the problems that arose in the review was that each study reported on the effects of different treatments, so it was not possible to evaluate the effect of the individual functional appliances against each other. However, they combined the data for the effects of the Herbst, Bass, and Bionator and compared them against the Twin Block.

The findings of this meta-analysis suggested that when compared against an untreated control, a functional appliance resulted in a reduction in overjet and a difference in ANB of -2.27 degrees. The interpretation of this effect is for the individual operator to decide if this is clinically significant. When the effect of the Twin Block against the other appliances was calculated, there were very modest effects on ANB (0.68 degrees) and no effect on overjet.

Incremental Advancement of Functional Appliances

When a functional appliance is prescribed for a patient, we have the choice of activating the appliance to either maximum advancement or in increments of a few millimeters. There are differing opinions as to the advantages and disadvantages of these two approaches, and until recently these opinions were based entirely on clinical opinion. For example Falck and Frankel (1989) suggested that incremental advancement resulted in improved patient speech and comfort, resulting in greater cooperation. Others recommended that maximal advancement resulted in an increased orthopedic effect (Pancherz 1982). This hypothesis has been tested in two clinical trials (Banks et al. 2004; Gill & Lee 2005). In the first trial, 203 patients were randomized to receive Twin Block treatment with either maximum advancement or advancement in 2-mm increments. They evaluated the effect of the two different treatment methods on (1) completion rate, (2) final skeletal pattern, and (3) duration of treatment, and found that there were no differences in these outcome measures between the two groups of patients.

In the second trial, Gill and Lee investigated a modification of the Twin Block appliance and randomly allocated 70 patients to receive treatment with either a maximally advanced Twin Block or with a Mini-Block appliance (Gill & Lee 2005). The latter appliance was a modified Twin Block with smaller blocks at 90 degrees to each other and advanced in 3-mm increments. They carried out a complex analysis of many cephalometric measurements, and they concluded that there were no real advantages of incremental

advancement. It, therefore, appears that both of these studies were in agreement and there is no advantage or disadvantage for either method of advancement of Twin Blocks.

Patient Values

To this point we have simply described values that are relevant to orthodontists, and increasingly there is a feeling that patient values should be considered, particularly when we are providing information to patients that will enable them to take informed decisions on their treatment. Examples of patient values are (1) cooperation, (2) completion rate, and (3) our patients' perceptions of the appliances. Unfortunately, there is often little easily accessible information available on this important data although it may sometimes be found by carefully reading the details of trials.

Completion Rate

Completion rate is considered when reporting most studies. For early treatment the non-completion rate from the North Carolina study was 21%, for Florida it was 24%, and for the UK multicenter it was 18%. It is interesting to note that for the treatment that was carried out in adolescence the discontinuation rate was higher; for the UK multicenter 25% of children did not complete the functional phase of treatment; and in the London Hospital study the drop out rate was 21%. There was only one study that compared the relative completion rates of fixed and removable functional appliances, and this revealed that noncompletion for a Herbst appliance was 13% and for the Twin Block was 33% (O'Brien et al. 2003c). A more recent study by Lee et al. (2007) has revealed that the noncompletion rate in a trial of the Dynamax and Herbst appliances was 9% for both appliances.

Patient Perceptions

The only study that collected information on the way that the patients felt about their appliances was the UK study comparing the Twin Block and Herbst appliances (O'Brien et al. 2003c). In this study, the investigator gave the patients a short questionnaire that sought information on how their appliances influenced factors such as school work, family life, ease of speaking, and interference with homework. The results were interesting in that the patients felt that the Twin Block was worse than the Herbst with respect to influence on eating, speaking, and discomfort, and they reported more embarrassment with their friends and families. This may also explain why there was a marked difference in completion rates for the two appliances in the study, as the Herbst appliance patients reported fewer problems with speaking and eating, which may have influenced cooperation.

Treatment with Headgear Provided During Adolescence

Headgear has been used for many years. Indeed, Edward Angle was quoted as saying in 1887 "*that the occipital bandage, as part of orthodontic treatment, was 'becoming more and more appreciated' when used for maxillary protrusion cases.* He felt, that following his experience of having used it *16 times*, that it was 'more satisfactory than any of the few devices' described in the literature" (Graber 1955). It is, therefore, surprising that this type of treatment has not been subjected to high-quality research. A systematic review

carried out in 2002 suggested that most of the “evidence” on the effectiveness of headgear has been derived from retrospective investigations (Atherton et al. 2002). Although this review was interesting, unfortunately they only reviewed literature after 1988 and did not report a significant earlier study (Jakobsson 1967). We have updated this review and found that while there have been several trials since then, they have been confined to comparison of different methods of Class II correction with headgear and other devices. Nevertheless, there were several studies that have evaluated early treatment, and these have been described previously in this chapter.

One trial was published as long ago as 1967 and must be considered to be a landmark study (Jakobsson 1967). The author divided sixty 8- to 9-year-old children into groups of three, which he referred to as triples, matched for dental development and malocclusion traits. One of the triples received treatment with an activator 11.5 hours per day for 18 months, one with a Kloehe bow cervical pull headgear for 12 hours per day for 18 months, and the final received no treatment and acted as a control. Jakobsson concluded that the headgear group demonstrated a posterior repositioning of the molar teeth by 3.7 mm and A point by -0.38 mm. This demonstrated that even though this amount of skeletal change is not really clinically significant, clearly there were valuable dental changes. Sadly, no other investigators have repeated this study, and orthodontists have had to rely on an evidence base derived from retrospective studies with historical controls or studies that have compared the effects of different types of headgear.

Even though these studies cannot be considered high-level evidence, it is perhaps useful to consider the findings that have evaluated the effects of different types of headgear. As with much orthodontic research, investigators have evaluated a multitude of outcome measures. In order to obtain clarity, we shall confine our discussion to distal movement of upper molar teeth and any recorded skeletal changes in the maxilla.

A fascinating, but unrepeatable, randomized study was carried out in 1978 by Melsen, in which 20 Scandinavian children aged between 8 and 10 years were randomized to receive two different types of cervical headgear (Melsen 1978). In one group the extra oral bow was bent upward by 20 degrees in relation to the occlusal plane, and in the other it was bent down by 20 degrees. The investigator then placed four metal implants into the maxilla and five metal implants into the mandible of the patients. Lateral cephalometric radiographs were taken at the start of treatment and then again after 3 months to check the stability of implants. All of the children “wore their headgear for exactly 12 hours per day” for the 8 months of the study.

The beauty of this experiment was that the movement of the respective jaws (represented by the implant lines) to the cranial base could be separated from movement of the teeth within the jaws, that is, the intramaxillary tooth movements. In the group in which the cervical headgear with the downward pointing bow was applied, 3.5 mm of the distal movement was recorded; however, most of this change was attributed to distal tilting of the molars. This would be expected with the particular bow design as the force was so far below the center of resistance of the tooth, generally thought to be in the trifurcation area. Where the extra oral bow was tilted up by 20 degrees to the inner bow, the distal movement was a much more modest 1.5 mm, but in this case there was insignificant tilting of the tooth. When they evaluated skeletal change, it appeared that this was a -0.75 degree reduction of SNA for the downward-pointing extra oral bow and a -1.5 degree reduction of SNA for the upward-tilting labial bow: again, differences that are unlikely to be of clinical significance.

Extrusion of molars was seen in both groups to a similar extent. This was one unexpected finding, as it was thought that the upward bow would extrude the teeth more than the downward-facing bow. The author proposed that occlusal forces and occlusal contacts may have a role in determining the effects of treatment and stated that mathematical calculations alone cannot solely be used to predict the results of headgear treatment. Individual adjustments were and always will be necessary, depending upon each patient's response to the therapy. The patients were all followed up with a further cephalometric radiograph when facial growth had largely ceased in late teens. In all but two cases, the change in growth direction, thought to be induced by the headgear, reverted back to the original, anterior growth direction.

The first authors to mention radiographic markers to help assess distalization of molar teeth were Altug and colleagues (2005) in a study in which they evaluated the effect of headgear on Class II cases that required unilateral molar distalization. They randomly assigned 10 patients to a group who were treated with asymmetric headgear attached to a removable plate; the other group of 10 were fitted with cervical headgear applied to another removable plate. Quite rightly, the authors felt they would have more chance of accurately identifying the magnitude of the distalization if they could separate the left from the right molars. This paper did not provide information on the duration of headgear wear or total treatment time. The authors reported that distalization was successfully achieved in all cases with means of distal movement of 4.1 mm and 2.3 mm with the asymmetric and cervical pull headgear, respectively. While this amount of dental movement is clearly desirable, it could be suggested that a proportion of this movement must be due to tipping, and the long-term stability of this movement could be questioned.

An unusual study was carried out by Sari et al. (2003) involving a rather unique Jasper Jumper (JJ)/removable plate system, whereby the active JJ preformed component was attached directly to removable plates, as was occipital pull headgear. The patients wore the appliances for 18 hours per day, and heavy headgear forces of 700 g per side were applied. The other study group in this RCT was treated with a Headgear Activator appliance, and again a heavy headgear force of 700 g was applied. Both groups were treated for an average of 8.5 months. The effects of treatment were compared with a group of similar patients who had declined treatment.

In both treatment groups there was significant molar distalization compared to the slight molar mesialization in the control. The final difference was 2.6 mm in the Activator HG group and 3.1 mm in the JJ/HG group. The authors reported that in every case a Class I skeletal pattern was achieved with a reduction of SNA of 1.1 and -0.5 degrees for the JJ and activator groups, respectively. They felt that the activator had a greater effect on the mandible, whereas the Jasper Jumper had a greater effect on the maxilla.

In a study that compared the effects of a functional regulator with straight-pull headgear, 84 patients were randomized to wear headgear for 14 hours per day or a Frankel FR appliance for 16 hours per day (Efstratiadis et al. 2005). In addition to evaluating the effects of treatment, they also aimed to compare the results that were achieved with regional and conventional superimpositions. When the data were analyzed, they excluded 19 of the patients who did not comply with treatment. As a result, they could not carry out an intention to treat analysis.

The concept underpinning the use of regional superimpositions was to allow a better understanding of conventional measurements by including the effects of structural displacements. They quite rightly point out that a decrease in SNA after headgear use could

be interpreted as posterior movement of A point, however a large contribution to this reduction may be from a downward movement of point A due to maxillary rotation. In addition, forward growth of nasion could also result in an observed SNA decrease. They found that A point moved -0.7 mm distally with the headgear and 1.2 mm forward with the Frankel. When molar movement was measured, the upper molars moved distally by 1.8 mm with the headgear, whereas with the Frankel they moved 1.1 mm mesially. Again, all these treatment effects were small.

A well-reported trial was carried out on forty 11-year-old Scandinavian children who received treatment either with a cervical headgear or an intraoral appliance comprising NiTi springs on a palatal wire between the molar and premolar or second deciduous molar bands (Bondemark & Karlsson 2005). The children wore the headgear for 10.8 hours per day with 400–500 g force. The intraoral appliance (IOA) was only activated once, on insertion, and required no further adjustments. There were no dropouts after randomization, although the authors noted there were four patients who refused to be included into the study at the outset.

The results of the study were that there was more effective distalization of the molars with the intra-oral appliance (3 mm) over 5.2 months, compared to a distalization of 1.7 mm over 6.4 months with the headgear. Interestingly, the overjet increased by 1 mm in the IOA because the Nance button failed to provide complete anchorage support. In the headgear group, the overjet actually decreased by 1 mm. There were no differences in the effects of the appliance on the maxilla; both appliances “moved” A point posteriorly by 0.8 mm.

Finally, a study was carried out by Benson et al. (2007), in which they compared two different methods of anchorage reinforcement in a series of “maximum anchorage” cases. The study involved 51 patients who were randomized to either headgear or placement of a midpalatal implant under local anesthesia. Following a 3-month healing period to allow osseointegration of the implant, forces were applied to the anchor unit via a custom-made palatal arch. They found that for the implant group, A point moved distally by -0.7 mm and distally by 0.3 mm for the headgear group. The upper molars moved distally by 1.5 mm for the implant and 3.0 mm for the headgear. None of the treatment changes between the groups were found to be statistically significant, however. They therefore concluded that that midpalatal implants were certainly as good a method of reinforcing anchorage as the more conventional anchorage method of providing extra oral support with headgear.

Synthesis of the Evidence

We can now summarize the information that we have on the treatment of children with increased overjets with the following conclusions.

1. The provision of early orthodontic treatment with either functional appliances or headgear does not achieve the aims of reducing treatment time, reducing extractions, and improving skeletal pattern when compared to single-phase treatment in adolescence.
2. While there may be some beneficial effect on a child's self-esteem, there are no significant differences ultimately in self-esteem between those children who have received two phases of treatment and those treated in one phase in adolescence.

3. Two-phase treatment undoubtedly involves more appointments, increased duration of overall treatment with all the associated risks, and increased cost to the health-care system or the individual.
4. When we consider treatment that is provided in adolescence, there appears to be some orthodontic growth modification from the use of a functional appliance, but the majority of the change is dentoalveolar. The use of headgear also provides limited skeletal change, and the greatest effect is dentoalveolar, with “distal” molar movement of up to 2 mm. Importantly, on average, this is not sufficient to correct a full-cusp Class II molar relationship.
5. It appears that with all functional appliance treatment, the average failure rate is about 20%. This should be considered when this treatment is offered to a patient, and it should be explained to the parents and the patients that only four out of five of these treatments will succeed. Unfortunately, there is no comparable data for headgear noncompliance.
6. When we consider patient values, it is fair to suggest that patients prefer fixed functional appliances as opposed to the Twin Block because of problems that arise from the bulky bite blocks. Furthermore, the cooperation rate with the fixed appliance appears to be greater. These appliances are, however, significantly more expensive, and cost should be considered in our discussions with patients and parents.

General Summary and the Way Forward

If we return to the questions that were raised at the beginning of this chapter, it appears that some important questions have been answered from studies providing high levels of evidence. Early treatment may not be worth the price that must inevitably be paid by the patients and the parents. However, patients and parents may elect to undergo early treatment for esthetic or psychosocial reasons. Functional appliances and headgear may both result in small amounts of skeletal change, which is welcome but not always considered clinically significant. But can we assume that this change will not be achieved by any other type of treatment? For example, will the prolonged application of Class II elastics as part of a course of fixed appliance treatment provide very similar results? As the current evidence in this area is lacking, it is probably appropriate to suggest that most operators are in equipoise about these competing treatments. It is therefore ethical to carry out RCTs to test the relative effects of these treatments. The main unanswered and important question concerns the effectiveness of providing treatment in adolescence versus orthognathic surgery when the patient is older. There is clearly a need for well-designed studies in the future to resolve this important question.

References

- Altug, H., Bengi, A.O., Akin, E. et al., 2005. Dentofacial effects of asymmetric headgear and cervical headgear with removable plate on unilateral molar distalization. *Angle Orthodontist* 75, pp. 584–592.

- Atherton, G.J., Glenny, A.M. & O'Brien, K., 2002. Development and use of a taxonomy to carry out a systematic review of the literature on methods described to effect distal movement of maxillary molars. *American Journal of Orthodontics* 29, pp. 211–216, discussion 195–196.
- Banks, P., Wright, J. & O'Brien, K., 2004. Incremental versus maximum bite advancement during twin-block therapy: a randomized controlled clinical trial. *American Journal Orthodontics and Dentofacial Orthopedics* 126, pp. 583–588.
- Benson, P., Tinsley, D., O'Dwyer, J. et al., 2007. Midpalatal implants vs headgear for orthodontic anchorage—a randomized clinical trial: cephalometric results. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 606–615.
- Bondemark, L. & Karlsson, I. 2005. Extraoral vs intraoral appliance for distal movement of maxillary first molars: a randomised controlled trial. *Angle Orthodontist* 75, pp. 699–706.
- Courtney, M., Harkness, M. & Herbison, P., 1996. Maxillary and cranial base changes during treatment with functional appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* 109, pp. 616–624.
- Cura, N. & Sarac, M., 1997. The effect of treatment with the Bass appliance on skeletal Class II malocclusions: a cephalometric investigation. *European Journal of Orthodontics* 19, pp. 691–702.
- Dolce, C., McGorray, S.P., Brazeau, L. et al., 2007. Timing of Class II treatment: skeletal changes comparing 1-phase and 2-phase treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 481–489.
- Efstratiadis, S., Baumrind, S., Shofer, F. et al., 2005. Evaluation of Class II treatment by cephalometric regional superpositions versus conventional measurements. *American Journal of Orthodontics and Dentofacial Orthopedics* 128, pp. 607–618.
- Falck, F. & Frankel, R., 1989. Clinical relevance of step-by-step mandibular advancement in the treatment of mandibular retrusion using the Frankel appliance. *American Journal of Orthodontics and Dentofacial Orthopedics* 96, pp. 333–341.
- Gill, D.S. & Lee, R.T., 2005. Prospective clinical trial comparing the effects of conventional Twin-block and Mini-block appliances: part 1. Hard tissue changes. *American Journal of Orthodontics and Dentofacial Orthopedics* 127, pp. 465–472, quiz p. 517.
- Graber, T., 1955. Extraoral force—facts and fallacies. *American Journal of Orthodontics and Dentofacial Orthopedics* 41, pp. 490–505.
- Harrison, J.E., O'Brien, K.D. & Worthington, H.V., 2007. Orthodontic treatment for prominent upper front teeth in children. *Cochrane Database Systematic Reviews* CD003452.
- Hayes, J.L., 2009. Problems with RCT design. *American Journal of Orthodontics and Dentofacial Orthopedics* 136, pp. 143–144, author reply 144–145.
- Illing, H.M., Morris, D.O. & Lee, R.T., 1998. A prospective evaluation of Bass, Bionator and Twin block appliances. Part I—The hard tissues. *European Journal of Orthodontics* 20, pp. 501–516.
- Jakobsson, S., 1967. Cephalometric evaluation of treatment effect on Class II, Division I malocclusions. *American Journal of Orthodontics and Dentofacial Orthopedics* 53, pp. 446–457.
- Lee, R.T., Kyi, C.S. & Mack, G.J., 2007. A controlled clinical trial of the effects of the Twin block and Dynamax appliances on the hard and soft tissues. *European Journal of Orthodontics* 29, pp. 272–282.
- Mao, J. & Zhao, H., 1997. The correction of Class II, Division 1 malocclusion with bionator headgear combination appliance. *Journal of Tongji Medical University* 17, pp. 254–256.
- Melsen, B., 1978. Effects of cervical anchorage during and after treatment an implant study. *American Journal of Orthodontics and Dentofacial Orthopedics* 73, pp. 526–540.
- Morris, D.O., Illing, H.M. & Lee, R.T., 1998. A prospective evaluation of Bass, Bionator and Twin Block appliances. Part II—The soft tissues. *European Journal of Orthodontics* 20, pp. 663–684.

- O'Brien, K., Wright, J., Conboy, F., et al. 2009. Early treatment for Class II Division 1 malocclusion with the Twin-Block appliance: a multi-center, randomized, controlled trial. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, 573–579.
- O'Brien, K., Wright, J. & Conboy, F., 2003a. Effectiveness of early orthodontic treatment with the Twin-block appliance: a multicenter, randomized, controlled trial. Part 2: Psychosocial effects. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 488–494, discussion 494–495.
- O'Brien, K., Wright, J., & Conboy, F., 2003b. Effectiveness of early orthodontic treatment with the Twin-block appliance: a multicenter, randomized, controlled trial. Part 1: Dental and skeletal effects. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 234–243, quiz 339.
- O'Brien, K., Wright, J., & Conboy, F., 2003c. Effectiveness of treatment for Class II malocclusion with the Herbst or Twin-block appliances: a randomized, controlled trial. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 128–137.
- Pancherz, H., 1982. The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. *American Journal of Orthodontics and Dentofacial Orthopedics* 82, pp. 104–113.
- Pavlow, S.S., McGorray, S.P. & Taylor, M.G., 2008. Effect of early treatment on stability of occlusion in patients with Class II malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics* 133, pp. 235–244.
- Richmond, S., Shaw, W.C. & O'Brien, K.D., 1992. The development of the PAR Index (Peer Assessment Rating): reliability and validity. *European Journal of Orthodontics* 14, pp. 125–139.
- Sari, Z., Goyenc, Y., Doruk, C. et al., 2003. Comparative evaluation of a new removable Jasper Jumper functional appliance vs an activator-headgear combination. *Angle Orthodontist* 73, pp. 286–293.
- Trenouth, M.J., 2009. Design flaws in some randomized controlled trials. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, p. 141.
- Tulloch, J.F., Medland, W. & Tuncay, O.C., 1990. Methods used to evaluate growth modification in Class II malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics* 98, pp. 340–347.
- Tulloch, J.F., Proffit, W.R. & Phillips, C., 2004. Outcomes in a 2-phase randomized clinical trial of early Class II treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 125, pp. 657–667.
- Wheeler, T.T., McGorray, S.P., Dolce, C., et al. 2002. Effectiveness of early treatment of Class II malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics* 121, pp. 9–17.

External Root Resorption and Orthodontic Treatment— Assessment of the Evidence

Belinda J. Weltman, BHsc, MSc, BDent, MS (Orth),
FRCD(C)
Vancouver, BC

Despite the extensive amount of research that has been conducted, it is unknown how orthodontic treatment influences root resorption. The etiological factors are complex and multifactorial, but it appears that apical root resorption results from a combination of individual biological variability and the effect of mechanical stimulus.

The aim of this chapter is to review the existing literature on orthodontically induced inflammatory root resorption (OIIRR). It will begin by providing background information on the etiology of external apical root resorption, followed by an examination of the prevalence of OIIRR and a discussion of the limitations with our various detection methods for root resorption. Evidence examining the association between root resorption and orthodontic treatment will be based on a systematic review of the literature organized by patient-related risk factors and orthodontic treatment-related risk factors. Results from randomized controlled trials will be highlighted in the review, and any conclusions presented will be based on following the research findings through the hierarchy of evidence. Prevention and treatment options for OIIRR based on the existing evidence will be discussed. A general summary with recommendations for future research will be provided.

Background and Etiology of External Apical Root Resorption

Root resorption (RR) is defined as microscopic areas of resorption lacunae visualized with histological techniques (Hartsfield et al. 2004).

The etiology of root resorption requires two phases: injury to the external surface of the root yielding denuded mineralized tissue and extended stimulation of multinucleated cells (Trope 1998). Denuded, mineralized tissue is colonized by multinucleated cells that initiate the resorption process. Without further stimulation, spontaneous repair will occur with cementum-like material within 2–3 weeks (surface resorption). However, if the stimuli remain, the inflammatory process on the denuded root will persist, and when it involves the deeper root dentin, it can then be detected radiographically (Fuss et al. 2003).

Apical root resorption may be observed during or at the end of treatment. Root resorption begins approximately 2–5 weeks into treatment, but it takes 3–4 months before it can be detected radiographically (Figure 5.1). It is a complex biological process for which many aspects remain unclear but that occurs when forces created at the root apex exceed the resistance and reparative ability of the periapical tissues (Parker & Harris 1998).

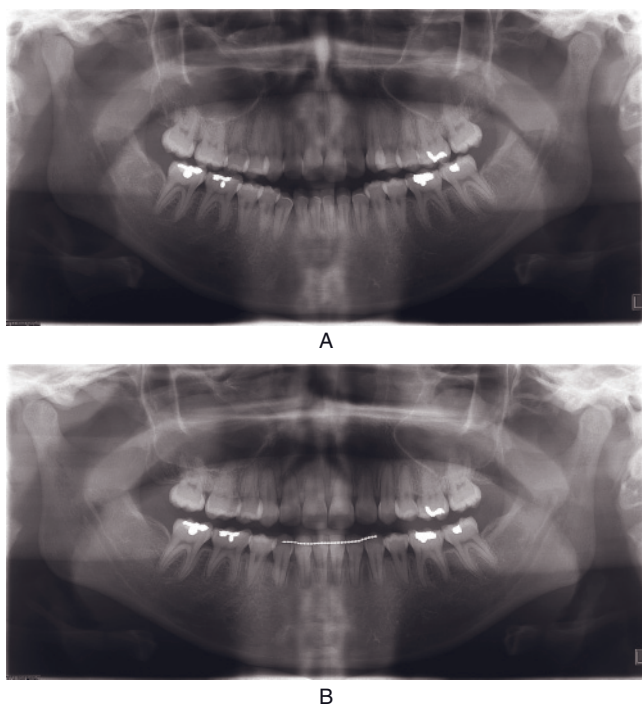


Figure 5.1 (a) Pretreatment radiograph of a 22-year-old female with crowding and protrusion necessitating orthodontic treatment with extraction of four first premolars. (b) Active root resorption can be seen in this immediate posttreatment radiograph. Shortening of the root has occurred as a result of resorptive cavities coalescing at the apex, cutting off peninsulas of root structure.

There are three types of orthodontically induced inflammatory root resorption (OIIRR), and severity is determined by the extent to which root tissue is involved (Trope 1998; Brezniak & Wasserstein 2002a).

- **Surface resorption:** Only the outer cemental layers are resorbed and are then fully regenerated or remodeled once the etiologic factor has been removed.
- **Deep resorption:** The cementum and outer layers of dentin are resorbed and are usually repaired with cementum material. The final shape of the root after this resorption and formation process may or may not be identical to the original form.
- **Circumferential apical root resorption:** Tridimensional resorption of the hard tissue components of the root apex occurs, and root shortening is evident. When the root loses apical material beneath the cementum, no regeneration is possible and the resorption is irreversible, although sharp edges may remodel.

Orthodontic forces create pressure and tension zones within the periodontal ligament, resulting in an infiltration of osteoclasts into the area of compression, which then resorb bone. The necrotic tissue must be removed before tooth movement can progress. It accounts for the initial delay in orthodontic treatment and always precedes the root resorption process; it has been seen close to areas of root resorption coinciding with the pressure zones of the periodontal ligament (Kurol & Owman-Moll 1998).

These forces also act on cementum, which is more resistant to resorption than bone (Brezniak & Wasserstein 1993). In OIIRR the injury results from the pressure applied to the root during tooth movement. This pressure produces ischemic necrosis of the periodontal ligament (PDL) localized in the pressure area (Trope 1998; Brezniak & Wasserstein 2002a). Macrophage-like and multinucleated cells are activated by biochemical signals derived from the sterile necrotic tissue. The initial elimination of necrotic tissue takes place at the periphery of the hyaline zone. During removal of the hyaline zone, the nearby outer surface of the root can be damaged (Brezniak & Wasserstein 1993; Brudvik & Rygh 1994; Brezniak & Wasserstein 2002a). In severe cases the orthodontic pressure may directly damage the outer root surface, including cementoblasts and precementum layers. Macrophage and multinucleated cell activity continues until no hyaline tissue is present and/or the force level decreases. Resorption lacunae expand the root surfaces involved and thereby indirectly decrease the pressure exerted through force application. Thus, the decompression allows the process to reverse and the cementum to be repaired (Trope 1998; Brezniak & Wasserstein 2002a).

If the orthodontic forces are applied for several hours, multinucleated positive cells develop odontoclastic-like morphology and functions and begin a complete cementum resorption, denuding mineralized dentin areas (Brudvik & Rygh 1994; Brezniak & Wasserstein 2002a). At this stage the resorption is still reversible provided that the pressure exerted by the orthodontic force stops and the extension of the root-damaged area is limited.

In severe injuries, in which the damaged area is large or the time of the force application is long, multinucleated cells continue the resorptive process, also including the exposed dentin. Odontoclasts, which were activated by the persistence of the inflammation, produce a tridimensional, nonreversible, and radiographically evident root resorption (Figure 5.2) (Brezniak & Wasserstein 1993; Brudvik & Rygh 1994; Brezniak & Wasserstein 2002a).

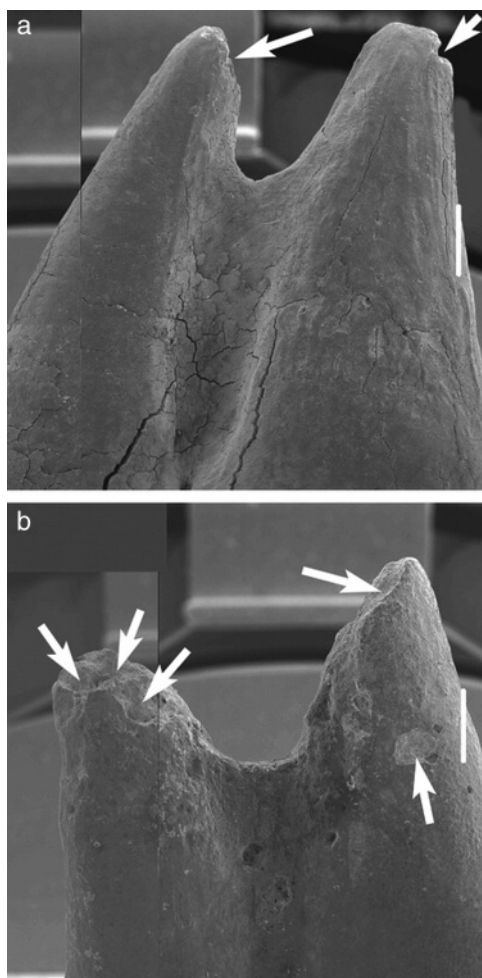


Figure 5.2 Varying severity of root resorption in intruded teeth (15 $\times$). (a) Minor root resorption (see the arrows). (b) Severe root resorption (see the arrows). From Han, G. et al., 2005. Root resorption after orthodontic intrusion and extrusion: an intraindividual study. *Angle Orthodontist*, 75, 912–918. With permission from the E. H. Angle Education and Research Foundation.

Following termination of orthodontic forces, root resorption typically ceases, and a progressive remodeling and reparative process of the root surface is evident. According to Schwartz (1932), this occurs when pressure falls below the optimal forces of 20–26 g/cm². The resorption lacunae are filled in with new secondary cementum during periods of relative quiescence. Different spatial repair patterns have been reported, proceeding either from the periphery of the resorption cavity or from within the center (Owman-Moll & Kurol 1998). Repair areas also exhibit many combinations of cellular (fast process trapping cells) and acellular (slow process) cementum (Figure 5.3). However, if an island of cemen-

tum or dentine becomes separated from the root surface, it will be resorbed, and repair of the damaged root will be impossible (Proffit et al. 2006).

Prevalence and Detection of Orthodontically Induced Inflammatory Root Resorption

Histological studies report a greater than 90% occurrence of RR in orthodontically treated teeth (McLaughlin 1964; Stenvik & Mjor 1970; Harry & Sims 1982). In most cases the loss of root structure is minimal and clinically insignificant. Lower percentages are reported when diagnostic radiographic techniques are used. Lupi et al. (1996) reported the incidence of external apical root resorption (EARR) before treatment is 15% and after treatment, 73%.

Using panoramic or periapical radiographs, the average OIIRR is usually less than 2.5 mm (Linge & Linge 1983; Linge & Linge 1991; Mirabella & Artun 1995; Mavragani et al. 2000; Sameshima & Sinclair 2001a), or varies from 6 to 13% for different teeth (Blake et al. 1995).

Using graded scales, OIIRR is usually classified as minor or moderate in most orthodontic patients (Levander & Malmgren 1988; Janson et al. 1999; McNab et al. 1999; Brin et al. 2003). Severe resorption defined as exceeding 4 mm or one-third of the original root length is seen in 1–5% of teeth (Linge & Linge 1983; Levander & Malmgren 1988; Lupi et al. 1996; Taithongchai et al. 1996; Levander, Malmgren & Stenback 1998; Janson et al. 1999; McNab et al. 1999; Killiany 2002).

Regardless of genetic or treatment-related factors, the maxillary incisors consistently average more apical root resorption than any other tooth (Figure 5.4), followed by mandibular incisors and mandibular first molars (Newman 1975; Goldson & Henrikson 1975; Malmgren et al. 1982; Kennedy et al. 1983; Linge & Linge 1991; Kaley & Phillips 1991; Harris et al. 1997; Janson et al. 1999; Sameshima & Sinclair 2001a; Brin et al. 2003; Kook et al. 2003).

This may be because the extent of orthodontic movement of these teeth is usually greater than in the rest of the dentition, and the characteristic root structure of the incisors, along with their relationship to bone and the periodontal membrane, tends to transfer most of the forces to the apex (English 2001).

Adequacy of 2-D Radiographs to Analyze Root Resorption

The detection of RR has been mainly through radiographs, light microscopes, scanning electron microscopes, and micro-CT. Panoramic radiographs have been found to overestimate the amount of root loss by 20% or more when compared with periapical radiographs (PAs) (Sameshima & Sinclair 2001a). Although the paralleling technique with PAs has been described as the technique of choice for detecting root shortening, it has also been shown to be geometrically inaccurate (Katona 2006).

Periapical radiographs have been criticized as inaccurate in the assessment of root resorption (Katona 2006). It is believed that the compensatory algorithms are intrinsically ambiguous and incapable of reliably identifying constant length roots (nonresorbing and nongrowing), even in explicitly defined “perfect” teeth, and are further compromised by landmark identification.

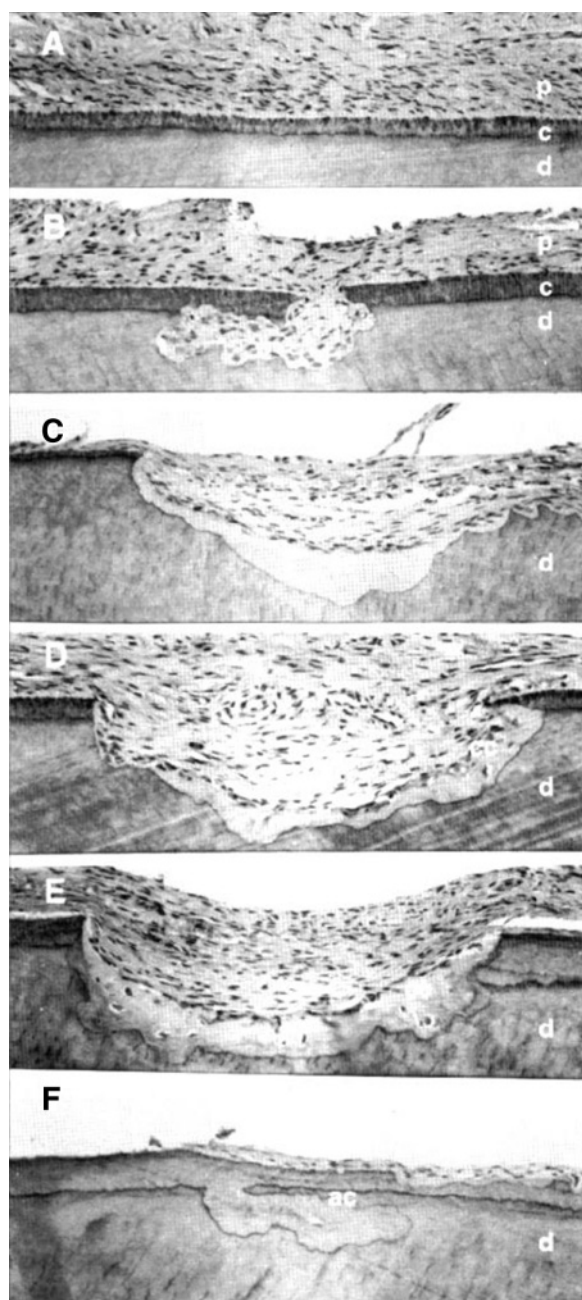


Figure 5.3 Histological illustration of varying degrees of repair in orthodontically induced root resorption in maxillary premolars after 1 to 8 weeks in retention. (A) Root surface in the cervical third of the root with normal dentin, acellular root cementum, and periodontal ligament. (B) Undermined root resorption in the cervical third of the root with no repair. (C) Partial repair with acellular cementum in the cervical third of the root. (D) Partial repair with cellular cementum in the cervical third of the root. (E) Total repair of the root surface with cellular cementum, but root contour has been altered. (F) Total repair of the root surface with acellular cementum, and original root contour was reestablished. Abbreviations: acellular root cementum, ac; cellular cementum, cc; cementum, c; dentin, d; periodontal ligament, p. From Owman-Moll, P., Kurol, J. & Lundgren, D, 1995b. Repair of orthodontically induced root resorption. *Angle Orthodontist*, 65(6), pp. 403–408. With permission from the E. H. Angle Education and Research Foundation.

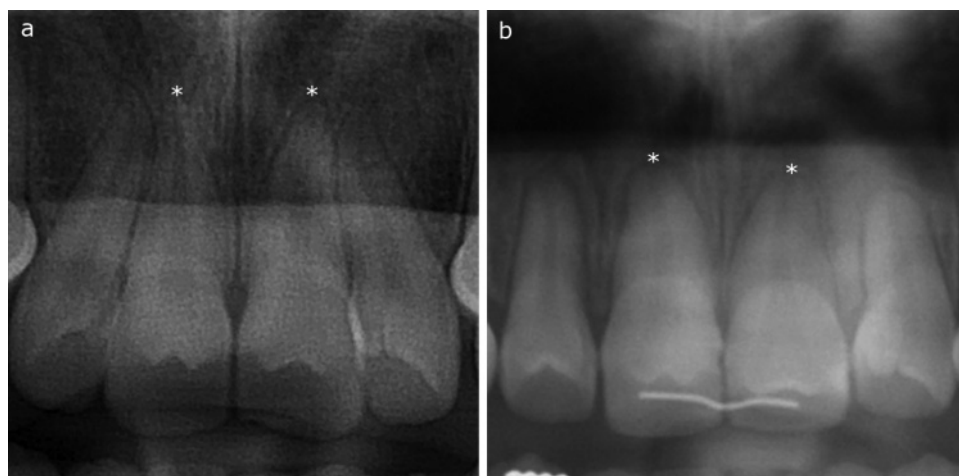


Figure 5.4 Pretreatment (a) and posttreatment (b) panoramic radiographs of a 12-year-old female with bimaxillary protrusion who experienced moderate root resorption of her maxillary incisors during orthodontic treatment.

Lateral skull cephalometric radiographs have been shown to yield an accurate and reproducible view of upper incisor length, but is subjected to a 5–12% enlargement factor as a result of the radiographic set up (Chan & Darendeliler 2004b). Also, overlapping of the right and left side make the individual images unclear. While radiography is a valuable diagnostic tool in detecting RR, quantitative measurements are relatively poor and should be avoided (Chan & Darendeliler 2004b).

Clinically, radiographs are an important diagnostic tool in detecting OIIRR, but the varying degrees of magnification, and the limitations involved with 2-D measurement of a 3-D phenomenon make the quantitative value of radiographs questionable and geometrically inaccurate (Sameshima & Sinclair 2001a; Chan & Darendeliler 2004b; Katona 2006). Quantitative 3-D volumetric evaluation of root resorption craters has been found to be a

feasible alternative with a high level of accuracy and repeatability (Chan et al. 2004a; Chan & Darendeliler 2004b; Darendeliler et al. 2004; Chan & Darendeliler 2006). A mathematical computer-based reconstruction of pre- and posttreatment dental images have also been shown to be a reliable technique for measuring root resorption (Reukers et al. 1998). It is important that future studies use accurate, reliable, and valid measurement tools so meaningful comparisons can be made.

Evidence for the Association Between Root Resorption and Orthodontic Treatment

Even in the absence of orthodontic treatment, root resorption can and does occur (Al-Nazhan 1991; Counts & Widlak 1993; Rivera & Walton 1994; Snelgrove 1995).

Patient-Related Risk Factors

Individual susceptibility is considered a major factor in determining root resorption potential with or without orthodontic treatment (Segal et al. 2004; Hartsfield et al. 2004; Pizzo et al. 2007).

History of Root Resorption

There is a high correlation between the amount (number of teeth involved) and the severity of root resorption present at the start of treatment to the root resorption present when the orthodontic appliance is removed (Brezniak & Wasserstein 1993, Drysdale et al. 1996; Hamilton & Gutmann 1999; Hartsfield et al. 2004).

Tooth Root Morphology

Through mostly observational studies, abnormal root shape and other dental anomalies have been reported as risk factors for OIIRR (Levander & Malmgren 1988; Kjaer 1995; Thongudomporn & Freer 1998; Sameshima & Sinclair 2001a; Sameshima & Sinclair 2004; Smale et al. 2005). However, other investigators have found no significant correlation between tooth anomalies and OIIRR (Lee et al. 1999; Brin et al. 2003) or significant correlations between peg-shaped roots or microdontia of lateral incisors and OIIRR (Kook et al. 2003).

There is a common belief that short roots undergo more resorption (Newman 1975; McFadden et al. 1989). A more recent study supports the opposite view; the tendency for resorption increases with increasing tooth length (Mirabella & Artun 1995). A possible explanation may be that long teeth need stronger forces to be moved, so the actual displacement of the root apex is greater during torquing movements (English 2001).

Genetic Influences

Several studies support the idea that there is a genetic influence on OIIRR (Harris et al. 1997; Hartsfield et al. 2004; Ngan et al. 2004). A study of 123 sibling pairs treated with the same technique by a single operator showed that there were significantly greater variances among than within sibling pairs (Harris et al. 1997).

More recently, OIIRR has been linked to the *IL-1B* gene, substantiating an important genetic predisposition to this problem. It has been observed that the presence of *IL-1B* allele 1 is associated with a high risk of OIIRR (homozygous has 5.6 times increased risk than nonhomozygous [Al-Qawasmi et al. 2003a]).

Another candidate gene for EARR is *TNFRSF11A*, or another genetic locus found at the D18s64 polymorphic marker level, that encodes a TNF receptor that mediates signaling leading to osteoclastogenesis contributing to OIIRR during orthodontic treatment (Al-Qawasmi et al. 2003b).

Sameshima and Sinclair (2001a) reported that Asian patients have significantly less root resorption than Caucasian or Hispanic patients. However, the statistical analysis on these data does not clearly show whether this is due to genetic factors or to differences in orthodontic treatment approaches (Bollen 2002).

Systemic Factors

It has been demonstrated that root resorption can be reduced with the use of drugs and hormones.

Drug-Related Resorption The main drug employed for resorption is bisphosphonate, which demonstrate a dose-dependent reduction of root resorption when administered in rats (Adachi et al. 1994; Igarashi et al. 1996). However, it has also been demonstrated that these drugs produce cemental surface alterations by inhibiting acellular cementum formation, increasing the vulnerability of the dental root to the resorptive process (Attati & Hammarstrom 1996a; Attati et al. 1996b).

Nabumetone, a drug belonging to the NSAID group, reduces the amount of root resorption along with the control of pain from intrusive orthodontic forces without affecting the pace of tooth movement (Villa et al. 2005).

Hormone Deficiency It is thought that endocrine disturbances including hypothyroidism and hypopituitarism may play a role in the occurrence of root resorption.

In rats it has been demonstrated that administration of L-thyroxine increases the resistance of cementum and dentin to osteoclastic activity (Poumpros et al. 1994). Shirazi et al. (1999) found that the administration of increased doses of L-thyroxine to rats resulted in the reduction of the extent of root resorption.

A reduction of root resorption in humans was reported after the administration of the thyroid hormone thyroxine in three patients with no thyroid conditions (Loberg & Engstrom 1994; Christiansen 1994). These results must be interpreted with caution when considering thyroxine administration to orthodontic patients as no randomized clinical human trials looking at L-thyroxine have been reported.

Asthma It was recently reported that patients with chronic asthma have an increased incidence of EARR that is confined to the maxillary molars. This finding may result from the close proximity of the roots to the inflamed maxillary sinus and the presence of inflammatory mediators in these patients (McNab et al. 1999; Brezniak & Wasserstein 2002b). The inflammatory mediators produced in asthma may enter the periodontal ligament and act synergistically to increase susceptibility to resorption. Although the asthma group had elevated incidence of EARR, both asthmatics and healthy patients exhibited similar amounts of moderate and severe resorption (McNab et al. 1999).

Root Proximity to Cortical Bone It is unclear if proximity to cortical bone is related to root resorption. Kaley and Phillips (1991) reported that the risk of root resorption was 20 times greater when the maxillary incisors were in close proximity to the cortical plate, but roots were assessed with panoramic radiographs and cortical plates were assessed with lateral skull cephalograms. A similar study that used only cephalometric radiographs reported a much weaker correlation between the proximity of the root and cortex with the degree of OIIRR (Horiuchi et al. 1998). Another study using only cephalometric analysis failed to show any association (Otis et al. 2004).

Alveolar Bone Density It had been postulated that tooth movement in dense bone requires greater or longer force application and consequently results in more root resorption (Rygh & Reitan 1972). In a rodent model, teeth were shown to move faster and still develop OIIRR in animals that had an induced decrease in bone density (Goldie & King 1984). A similar study in beagle dogs showed that tooth movement was slower in denser dentoalveolar complexes (Midgett et al. 1981).

In a human study, the amount of alveolar bone around the root, thickness of cortical bone, density of the trabecular network, and fractal dimension showed no significant correlation with the extent of the OIIRR (Otis et al. 2004).

Chronic Alcoholism Chronic alcoholics receiving orthodontic treatment are at a high risk of developing severe root resorption during the course of orthodontic treatment (Davidovitch et al. 1996).

Previous Trauma

Historically, there has been a belief, based mostly upon observational data and animal studies, that all teeth with a previous history of trauma are more susceptible to OIIRR than healthy control teeth (Linge & Linge 1983; Linge & Linge 1991; Andreassen 1985).

Other investigators have reported that teeth with slight to moderate injuries may not have any greater tendency for root resorption during orthodontic treatment than do uninjured teeth (Malmgren et al. 1982). Data from a recent systematic review included three randomized clinical trials (RCTs) that met inclusion criteria. Incisors with clinical signs or patient reports of trauma (but no signs of EARR) had essentially the same prevalence of moderate to severe OIIRR as those without trauma (Levander, Malmgren & Eliasson 1994; Brin et al. 2003; Mandall et al. 2006).

There is a lack of RCTs that examine patients with previously traumatized teeth that have exhibited root resorption before orthodontic treatment. Observational data indicate orthodontic tooth movement will contribute to the resorptive process. (Brezniak & Wasserstein 1993; Drysdale et al. 1996; Hamilton & Gutmann 1999; Hartsfield et al. 2004).

Endodontic Treatment

Some investigators have reported an increased frequency of resorption in endodontically treated teeth (Wickwire et al. 1974).

It has been demonstrated that the endodontic treatment does not represent a risk factor for OIIRR. Teeth with previous root canal treatment exhibit a lesser propensity for apical root resorption during orthodontic tooth movement (Mirabella & Artun 1995; Drysdale

et al. 1996; Hamilton & Gutmann 1999; Brezniak & Wasserstein 2002b). It has been suggested that endodontically treated teeth are more resistant because of an increased dentine hardness and density (Remington et al. 1989).

Severity and Type of Malocclusion

The amount of orthodontic tooth movement is associated with the resulting EARR (Mirabella & Artun 1995; Parker & Harris 1998; Hartsfield et al. 2004; Segal et al. 2004; Fox 2005). In turn, the required amount of tooth movement is a function of the severity of the malocclusion, which makes the presence of a severe malocclusion a risk factor for EARR.

Class I patients with acceptable overjets were significantly less likely to show EARR than were Class II or III patients (Kaley & Phillips 1991).

Significant associations between EARR and the magnitude of overjet reduction during treatment have been found (Baumrind et al. 1996; Sameshima & Sinclair 2001a; Brin et al. 2003; Hartsfield et al. 2004) but not by all investigators (Linge & Linge 1983). Class II, division 1 patients experienced significantly more RR (mean 2 mm) than did Class I patients (mean 1 mm) undergoing orthodontic treatment with first premolar extraction, although no significant differences were found between the amount of RR and tooth inclination or duration of active treatment (Taner et al. 1999).

Patients undergoing extractions during orthodontics had greater root resorption, which may be related to longer treatment duration and an increased amount of tooth movement (Sameshima & Sinclair 2001b).

Patient Age

There was a traditional belief that OIIRR increases with age (Reitan 1974; Linge & Linge 1983). More recent observational and retrospective data have shown no effect of age on RR (McFadden et al. 1989; Harris & Baker 1990; Linge & Linge 1991; Harris et al. 1993; Beck & Harris 1994; Bishara et al. 1999; Baumrind et al. 1996; Sameshima & Sinclair 2004). The only RCT that has examined this topic also concluded that patient age did not play a significant role in OIIRR (Scott et al. 2008).

Investigations have also found that the risk of OIIRR is lower in patients treated before the age of 11 years. Roots that were incompletely developed before treatment reached a significantly greater length than those that were fully developed at the start of treatment (Linge & Linge 1983; Mavragani et al. 2002). Perhaps the layer of thick pre-dentine on underdeveloped roots provides a preventive effect.

Gender

There does not appear to be an association between gender and root resorption incidence or severity experienced during orthodontic treatment. Reports of a higher incidence in both females (Newman 1975; Kjaer 1995; Horiuchi et al. 1998) and males (Spurrier et al. 1990; Baumrind et al. 1996) exist. While other investigators have concluded there is no effect (McFadden et al. 1989; Harris et al. 1997; Parker & Harris 1998; Sameshima & Sinclair 2001a, Scott et al. 2008). After examining the existing observational and retrospective study data and the RCT data from Scott et al., it seems unlikely that gender is a risk factor for OIIRR.

Table 5.1 Risk factors for orthodontically induced inflammatory root resorption.

Likely Risk Factors

History of root resorption before orthodontic treatment
Previous trauma resulting in root resorption
Genetics:*IL-1B* allele 1, accountable for 15% variation *TNFRSF11A* gene*

Unclear Risk Relationship

Bisphosphonates
Hormone deficiency
Asthma
Root proximity to cortical bone
Chronic alcoholism
Severity/type of malocclusion

Unlikely Risk Factors

Nabumetone (likely protective)
Alveolar bone density
Tooth/root morphology
Previous trauma without root resorption
Endodontic treatment (likely protective)
Age
Gender

*Other factors to be identified, but evidence supports a link between genetics and OIIRR estimated to be over 50%.

There are many patient-related risk factors that may increase susceptibility for OIIRR. The current evidence available is conflicting and inconclusive. A summary of our current understanding of these factors can be found in Table 5.1, where the factors have been grouped into likely, unlikely, and unclear risk-relationship categories.

Orthodontic Treatment-related Risk Factors

Orthodontically induced inflammatory root resorption (OIIRR) is considered to be a particularly important sequelae associated with orthodontic treatment. It is widely accepted that properly executed, well-designed, randomized controlled trials provide the best evidence on the efficacy of health-care interventions. In spite of the considerable amount of OIIRR research reported in the scientific literature, the majority of clinical trials are not randomized, prospective, or representative of 24-month comprehensive orthodontic care. Moreover, in many studies the measurement techniques for OIIRR are not uniform or on similar teeth.

A recent systematic review looking at OIIRR identified 921 studies, but only 11 randomized controlled trials were considered appropriate for inclusion in the review (Figure 5.5), and their protocols were too variable to proceed with a quantitative synthesis/meta-analysis (Weltman et al. 2010). It was found that with the exception of the light-force group in one trial (Chan & Darendeliler 2006), all teeth experiencing orthodontic tooth movement had statistically significant more root resorption than control teeth in each of the 11 trials included in this review, although individual variation was large (Table 5.2).

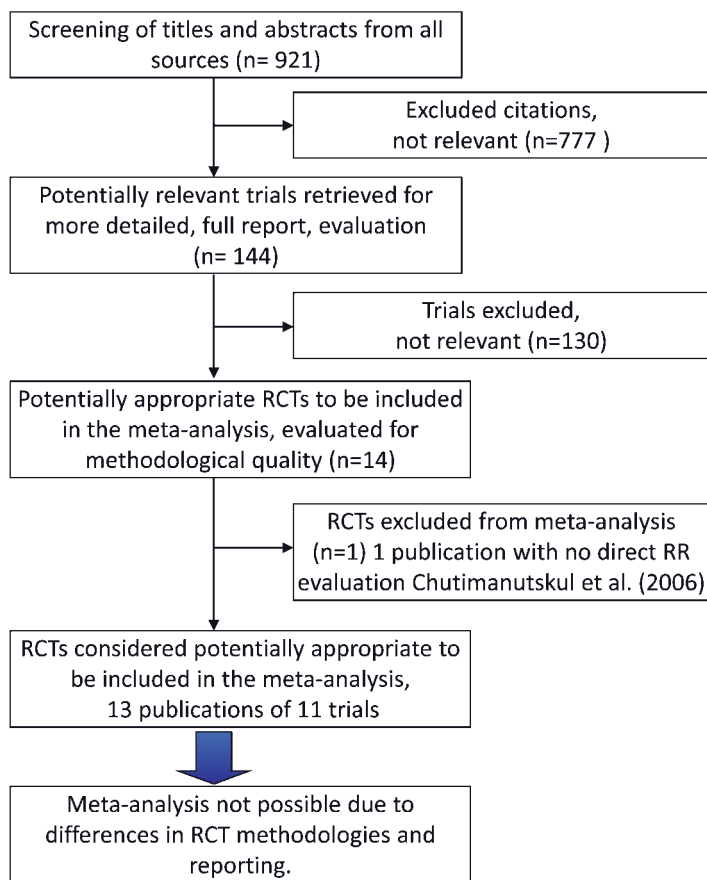


Figure 5.5 A QUOROM statement flow diagram outlining the systematic review of titles, abstracts, and full-text articles on root resorption and orthodontic treatment. From Weltman, B.J., Vig, K.W.L., Fields, H.W. et al. 2010. Root resorption associated with orthodontic tooth movement: a systematic review. *American Journal of Orthodontics and Dentofacial Orthopedics* 4, pp. 462–476. Courtesy of the American Journal of Orthodontics and Dentofacial Orthopedics.

Treatment Duration

Some studies have concluded that prolonged orthodontic treatment times result in increased incidence of apical root resorption (Deshields 1969; McFadden et al. 1989; Linge & Linge 1991; Baumrind et al. 1996; Brin et al. 2003; Segal et al. 2004; Otis et al. 2004; Fox 2005). The length of treatment has also been linked to the severity of root resorption (Casa et al. 2001; Jimenez-Pellegrin & Arana-Chavez 2004; Sameshima & Sinclair 2004). However, others found no significant association between OIIRR and treatment time (Dermaut & De Munck 1986; Levander & Malmgren 1988; Beck & Harris 1994).

Confounding variables such as more difficult treatment plans or lack of patient compliance may be associated with extended treatment durations, and these factors may also contribute to root resorption.

Table 5.2 Major methodological criteria and results from included RCTs in a systematic review examining OIIRR.

Study	Randomization	Allocation Concealed	Assessor Blinding	Drop outs Described	Risk of Bias	Study Results
Acar 1999	No	Unclear	Unclear	Yes	High	Teeth experiencing orthodontic movement had significantly more root resorption than control teeth. Continuous force produced significantly more root resorption than discontinuous force application.
Barbagallo 2008	Yes	No	No	Yes	Moderate	Heavy force produced significantly more root resorption than light force or thermoplastic appliance (TA) force application. Light force and TA force resulted in similar root resorption cemental loss, both statistically significant versus control.
Brin 2003	Yes	Yes	Yes	Yes	Low—retrospective	As treatment time increased, the odds of OIIRR also increased. The odds of a tooth experiencing severe root resorption were greater if a large reduction of overjet occurred during phase II. Incisors with clinical signs or patient reports of trauma had essentially the same prevalence of moderate to severe OIIRR as those without trauma. Teeth with roots having unusual morphology before treatment were not significantly more likely to have moderate to severe OIIRR than those with more normal root form.
Chan 2004b	Yes	No	No	Yes	Moderate	Heavy force application produced significantly more root resorption than light force application or control.
Chan & Darendeliler 2006	Yes	No	No	Yes	Moderate	The mean volume of the resorption crater in the light force group was 3.49 times greater than in the control group (not significant).

Han et al. 2005	Yes	Yes	Yes	Yes	Low	RR from extrusive force was not significantly different from the control group. Intrusive force significantly increased the percentage of resorbed root area.
Harris et al. 2006	Yes	No	No	Yes	Moderate	Heavy force application produced significantly more root resorption than light force application or control. The volume of root resorption craters after intrusion was directly proportional to the magnitude of the intrusive force.
Levander, Malmgren & Eliasson 1994	Yes	Unclear	Unclear	Yes	Moderate	The amount of root resorption was significantly less in patients treated with a pause than those treated with continuous forces without a pause. No statistically significant correlation was found between root resorption and angle classification, trauma history, extraction treatment, time with rectangular archwires, time with Class II elastics, or total treatment time.
Mandall et al. 2006	Yes	Yes	Yes	Yes	Low	History of incisor trauma was not associated with increased root resorption. No statistically significant difference between archwire sequences was found for upper-left central incisor root resorption or between the proportion of patients with/without root resorption.
Reukers et al. 1998	Yes	Yes	Yes	Yes	Low	Results showed no statistically significant differences in the amount of tooth root loss or prevalence of root resorption between straightwire and standard edgewise groups.
Scott et al. 2008	Yes	Unclear	Yes	Yes	Low	Mandibular incisor root resorption was not statistically different between self-ligating Damon 3 and conventional synthesis systems.

Data from Weltman BJ, Vig KWL, Fields HW, et al: Root resorption associated with orthodontic tooth movement: a systematic review. Am J Orthod Dentofacial Orthop, 2010.
With permission from the American Association of Orthodontists

Magnitude of Applied Force

In several randomized controlled trials, heavy force application produced significantly more root resorption than light force application or in controls (Chan et al. 2004a; Harris et al. 2006; Chan & Darendeliler 2006; Barbagallo et al. 2008). It is believed that higher stress causes more extensive root resorption because the rate of lacunae development is more rapid, and the tissue repair process is compromised (Casa et al. 2001; Faltin et al. 2001; Chan et al. 2004a; Chan & Darendeliler 2005; Chan & Darendeliler 2006; Harris et al. 2006; Barbagallo et al. 2008). Earlier nonrandomized studies contradict these findings. According to Owman-Moll et al. (1996a, b), when the force magnitude was doubled and quadrupled from 50 cN, there was no effect on the frequency or severity of root resorption or on the rate of tooth movement in his experiments. Although individual variations in root resorption and rate of tooth movement were large, normal individual variations may overshadow the effect of a doubled force magnitude. These results should be interpreted with caution as selection criteria for the premolars were not strict and external factors that might predispose teeth to RR were not excluded. Also, the accuracy of the serial sectioning protocol in identifying and measuring all craters was problematic, and craters could easily have been partially or even completely missed (Chan & Darendeliler 2005).

Direction of Tooth Movement

Studies examining intrusive force application have found significantly increased RR rates compared to controls (Han et al. 2005, Harris et al. 2006), whereas root resorption resulting from extrusive force was found to be no different from that in controls (Han et al. 2005). This is in agreement with previous literature indicating that greatest damage is observed with intrusive tooth movements because they concentrate pressure at the tooth apex (Kaley & Phillips 1991; Beck & Harris 1994; Parker & Harris 1998; Faltin et al. 2001; Han et al. 2005; Harris et al. 2006). When examining maxillary central incisors, movements torquing the apex lingually are strongly correlated with the onset of root resorption. In combination, intrusion and lingual root torque are the strongest causes of OIIRR (Kaley & Phillips 1991; Costopulos & Nanda 1996; Parker & Harris 1998).

Bodily movements are associated with a lower risk of OIIRR because the stress is distributed more evenly along the root (Parker & Harris 1998).

Amount of Apical Displacement

A meta-analysis reported by Segal and colleagues indicated that orthodontic inflammatory root resorption is correlated to the amount of apical displacement that occurs during treatment (Segal et al. 2004; Fox 2005).

Method of Force Application

Continuous Versus Discontinuous There is limited evidence that continuous forces produced significantly more root resorption than interrupted force application (Acar et al. 1999). This is in agreement with the results of studies with less rigorous designs that found that discontinuous force application results in lesser root resorption than the application of a continuous force (Faltin et al. 2001; Konoo et al. 2001; Weiland 2003). This is believed

possible because the pause in a discontinuous force allows the resorbed cementum to heal and prevents further resorption. This finding contradicts results from earlier, similar, non-randomized split-mouth experiments by Owman-Moll et al. (1995) where there was no difference in RR between teeth that were moved with either a continuous or an interrupted-continuous force. However, these results should be interpreted with caution, as force decay was evident in the springs used in the continuous force groups.

There is weak evidence that “jiggling” forces have a role in increasing root resorption, and as a result the use of removable appliances and intermaxillary elastics should be reduced (Linge & Linge 1983a, 1983b; Brezniak & Wasserstein 2002b).

Type of Appliance Rapid maxillary expansion, with cervical traction, has been implicated in severe maxillary first molar root resorption (Brezniak & Wasserstein 1993).

Less root resorption was observed in patients with removable appliances than with fixed appliances (Ketcham 1927).

There is limited evidence to suggest that both light forces and forces from thermoplastic appliances result in similar root resorption cemental loss, which was significantly more than seen in controls (Barbagallo et al. 2008). A recent longitudinal study of 100 consecutive Invisalign patients showed no measurable root resorption (Wheeler, unpublished data; Boyd 2007). There are no other strong studies that investigated this topic, but a case report has shown a significant EARR outcome with aligner treatment (Brezniak & Wasserstein 2008).

Treatment Technique When comparing straight-wire and standard edgewise techniques, no statistically significant differences in the amount of tooth root loss or prevalence of root resorption were observed between groups (Reukers et al. 1998). Some have suggested that the Begg technique may induce more harmful effects on the roots (Goldson & Henrikson 1975; TenHoeve & Mulie 1976; McNab et al. 2000). Other studies have suggested that there is no real significant difference between Begg, Tweed, or various straight-wire edgewise techniques (Malmgren et al. 1982; Lew 1990; Beck & Harris 1994; Alexander 1996; Parker & Harris 1998).

Bioefficient therapy using contemporary orthodontic materials was found to produce significantly less RR than simplified standard edgewise or edgewise straight-wire systems. It was believed that the use of heat-activated and superelastic wires and a smaller rectangular stainless steel wire during incisor retraction and finishing played a role in this finding (Janson et al. 1999).

When comparing conventional edgewise systems to various active and passive self-ligating appliances, a case-control study by Blake et al. (1995), a prospective clinical trial by Pandis et al. (2008), and a prospective clinical trial by Scott et al. (2008) found no statistically significant differences in root resorption between systems.

Prevention and Treatment Options for OIIRR

It is important to advise orthodontic patients of their risks before initiating treatment. A significant reduction in root length can cause an unfavorable crown/root ratio of the affected teeth, making them less suitable as abutments and anchorage for prosthetic restorations. Also, apical root loss of 3 mm is equivalent to 1 mm of crestal bone loss, so

periodontitis will progress more rapidly to a critical alveolar bone level if it involves teeth with root resorption (Kalkwarf et al. 1986)

During orthodontic treatment, if progress radiographs detect the early occurrence of OIIRR, there is evidence that halting active treatment for 2–3 months with passive archwires will lead to a decrease in the prevalence and severity of root resorption (Levander et al. 1994).

If severe resorption is identified, the treatment plan should be reassessed with the patient. Alternative options might include prosthetic solutions to close spaces, releasing teeth from active archwires if possible, interdental stripping instead of extractions, and early fixation of resorbed teeth (Brezniak & Wasserstein 2002b).

After treatment, if severe EARR is present on the final radiographs, follow-up radiographic examinations are recommended until the resorption has stabilized. Termination of active EARR usually occurs after appliance removal. If it does not occur, sequential root canal therapy with calcium hydroxide may be considered (Pizzo et al. 2007). After orthodontic treatment, some tooth mobility may occur, but only when 9 mm or more of the root has been resorbed (Levander & Malmgren 2000). Retaining the teeth with fixed appliances should be done with caution since occlusal trauma of the fixed teeth or segments might lead to extreme EARR (Brezniak & Wasserstein 2002b).

Long-term Prognosis

It has been found that root resorption associated with orthodontic treatment ceases with the termination of active treatment (Remington et al. 1989). When posttreatment root resorption does occur, it is not necessarily associated with large amounts of root resorption during the active treatment period. It is more likely associated with other factors, such as traumatic occlusion and active force-delivering retainers (Copeland & Green 1986).

Even extensive root resorption does not usually affect the functional capacity or greatly compromise the longevity of the teeth. An average-sized normally shaped maxillary central incisor that experienced no alveolar bone loss during orthodontic treatment, with a root shortened by 5 mm, will still have 75% of its periodontal attachment remaining (95% of patients), which explains why tooth loss due to apical shortening has not been reported in the literature (Kalkwarf et al. 1986).

A retrospective study, in which 100 patients were recalled 14 years after orthodontic treatments, reported no tooth loss and hypermobility in only two cases (Remington et al. 1989). A more recent retrospective analysis of patients who had experienced severe root resorption (root lengths 5.5–18.1 mm) recalled 5–15 years after treatment found that no teeth had mobility scores greater than 1 on Miller's index (crown deviates within 1 mm of its normal position), and no teeth had been lost (Levander & Malmgren 2000).

Summary and Future Directions

There is evidence that comprehensive orthodontic treatment causes an increase in the incidence and severity of root resorption and that heavy forces are particularly harmful.

There is no evidence that archwire sequencing, bracket prescription, or self-ligation affects OIIRR. There is also little evidence that previous trauma (with no history of EARR) or unusual tooth morphology play a role in increased OIIRR.

During orthodontic treatment, progress radiographs obtained after 6–12 months may detect early OIIRR. In patients in which OIIRR has been identified, there is some evidence that a 2–3 month treatment pause (with a passive archwire), will decrease further root resorption.

If severe resorption is identified, the treatment plan should be reassessed with the patient. Alternative options might include prosthetic solutions to close spaces, releasing teeth from active archwires if possible, stripping instead of extracting, and early fixation of resorbed teeth (Brezniak & Wasserstein 2002b).

After treatment, if severe OIIRR is present on the final radiographs, follow-up radiographic examinations may be recommended until the resorption has stabilized. Termination of active OIIRR usually occurs after appliance removal. If it continues, sequential root canal therapy with calcium hydroxide may be considered (Pizzo et al. 2007). Caution should be exercised when retaining the teeth with fixed appliances because occlusal trauma of the fixed teeth or segments might lead to extreme EARR (Brezniak & Wasserstein 2002b).

More evidence is required to determine risk factors identifying those susceptible to external apical root resorption and effective ways to decrease the severity and prevalence of EARR in the orthodontic population. There is a need for parallel group studies, with appropriate randomization, allocation concealment, and masking of outcome assessment. Such studies should be based on an estimated sample size calculation to ensure adequate power and be conducted over the full-length of orthodontic treatment.

The use of standardized techniques to measure root length/volume before and after treatment should be encouraged to provide a permanent record, allowing before and after comparisons of incidence and severity of root resorption with blinded assessors, error analysis, and consensus measures. Studies should also assess patient-centered outcomes, including the effect of severe root resorption on quality of life posttreatment and occurrence of further complications such as mobility and tooth loss. Other factors, such as genetic predisposition, and systemic factors should be assessed so that we may better understand how individual susceptibility affects the incidence and severity of OIIRR.

References

- Acar, A., Canyurek, U., Kocaaga, M. et al., 1999. Continuous vs. discontinuous force application and root resorption. *Angle Orthodontist* 69, pp. 159–163; discussion pp. 163–164.
- Adachi, H., Igarashi, K., Mitani, H. et al., 1994. Effects of topical administration of a bisphosphonate (risedronate) on orthodontic tooth movement in rats. *Journal of Dental Research* 73, pp. 1478–1486.
- Alexander, S.A., 1996. Levels of root resorption associated with continuous arch and sectional arch mechanics. *American Journal of Orthodontics and Dentofacial Orthopedics* 110, pp. 321–324.
- Al-Qawasmi, R.A., Hartsfield, J.K., Jr., Everett, E.T., et al. 2003a. Genetic predisposition to external apical root resorption. *American Journal of Orthodontics and Dentofacial Orthopedics* 123, pp. 242–252.
- Al-Qawasmi, R.A., Hartsfield, J.K., Jr., Everett, E.T. et al., 2003b. Genetic predisposition to external apical root resorption in orthodontic patients: linkage of chromosome-18 marker. *Journal of Dental Research* 82, pp. 356–360.

- Al-Nazhan, S., 1991. External root resorption after bleaching: a case report. *Oral Surgery, Oral Medicine, and Oral Pathology* 72, pp. 607–609.
- Andreasen, J.O., 1985. External root resorption: its implication in dental traumatology, paedodontics, periodontics, orthodontics and endodontics. *International Endodontic Journal* 18, pp. 109–118.
- Attati, I. & Hammarstrom, L., 1996a. Root surface defects in rat molar induced by 1-hydroxyethylidene-1, 1-bisphosphonate. *Acta Odontologica Scandinavica* 54, pp. 59–65.
- Attati, I., Hellsing, E. & Hammarstrom, L. 1996b. Orthodontically induced root resorption in rat molars after 1-hydroxyethylidene-1, 1-bisphosphonate injection. *Acta Odontologica Scandinavica* 54, pp. 102–108.
- Barbagallo, L.J., Jones, A.S., Petocz, P. et al., 2008. Physical properties of root cementum: part 10. Comparison of the effects of invisible removable thermoplastic appliances with light and heavy orthodontic forces on premolar cementum. A microcomputed-tomography study. *American Journal of Orthodontics and Dentofacial Orthopedics* 133, pp. 218–227.
- Baumrind, S., Korn, E.L. & Boyd, R.L., 1996. Apical root resorption in orthodontically treated adults. *American Journal of Orthodontics and Dentofacial Orthopedics* 110, pp. 311–320.
- Beck, B.W. & Harris, E.F., 1994. Apical root resorption in orthodontically treated subjects: analysis of edgewise and light wire mechanics. *American Journal of Orthodontics and Dentofacial Orthopedics* 105, pp. 350–361.
- Bishara, S.E., Vonwald, L. & Jakobsen, J.R., 1999. Changes in root length from early to mid-adulthood: resorption or apposition? *American Journal of Orthodontics and Dentofacial Orthopedics* 115, pp. 563–568.
- Blake, M., Woodside, D.G. & Pharoah, M.J., 1995. A radiographic comparison of apical root resorption after orthodontic treatment with the edgewise and speed appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* 108, pp. 76–84.
- Bollen, A.M., 2002. Large overjet and longer teeth are associated with more root resorption when treated orthodontically. *Journal of Evidence Based Dental Practice* 2, pp. 44–45.
- Boyd, R.L., 2007. Complex orthodontic treatment using a new protocol for the Invisalign appliance. *Journal of Clinical Orthodontics* 4, pp. 525–547.
- Brezniak, N. & Wasserstein, A., 1993. Root resorption after orthodontic treatment: part 1. Literature review. *American Journal of Orthodontics and Dentofacial Orthopedics* 103, pp. 62–66.
- Brezniak, N. & Wasserstein, A., 2002a. Orthodontically induced inflammatory root resorption. Part 1: the basic science aspects. *Angle Orthodontist* 72, pp. 175–179.
- Brezniak, N. & Wasserstein, A., 2002b. Orthodontically induced inflammatory root resorption. Part II: the clinical aspects. *Angle Orthodontist* 72, pp. 180–184.
- Brezniak, N. & Wasserstein, A., 2008. Root resorption following treatment with aligners. *Angle Orthodontist* 78, pp. 1119–1124.
- Brin, I., Tulloch, J.F.C., Koroluk, L. et al., 2003. External apical root resorption in Class II malocclusion: a retrospective review of 1- versus 2-phase treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 151–156.
- Brudvik, P. & Rygh, P., 1994. Multi-nucleated cells remove the main hyalinized tissue and start resorption of adjacent root surfaces. *European Journal of Orthodontics* 16, pp. 265–273.
- Casa, M.A., Faltin, R.M., Faltin, K., et al., 2001. Root resorptions in upper first premolars after application of continuous torque moment. Intra-individual study. *Journal of Orofacial Orthopedics* 62, pp. 285–295.
- Chan, E.K.M. & Darendeliler, M.A., 2005. Physical properties of root cementum: part 5. Volumetric analysis of root resorption craters after application of light and heavy orthodontic forces. *American Journal of Orthodontics and Dentofacial Orthopedics* 127, pp. 186–195.
- Chan, E.K.M. & Darendeliler, M.A., 2006. Physical properties of root cementum: part 7. Extent of root resorption under areas of compression and tension. *American Journal of Orthodontics and Dentofacial Orthopedics* 129, pp. 504–510.

- Chan, E.K.M., Darendeliler, M.A., Petocz, P. et al., 2004a. A new method for volumetric measurement of orthodontically induced root resorption craters. *European Journal of Oral Science* 112, pp. 134–139.
- Chan, E.K.M. & Darendeliler, M.A., 2004b. Exploring the third dimension in root resorption. *Orthodontics & Craniofacial Research* 7, pp. 64–70.
- Christiansen, R.L., 1994. Commentary: Thyroxine administration and its effects on root resorption. *Angle Orthodontist* 64, pp. 399–400.
- Chutimanutskul, W., Ali Darendeliler, M., Shen, G. et al. 2006. Changes in the physical properties of human premolar cementum after application of 4 weeks of controlled orthodontic forces. *European Journal of Orthodontics* 4, pp.313–318.
- Copeland, S. & Green, L.J., 1986. Root resorption in maxillary central incisors following active orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 89, pp. 51–55.
- Costopoulos, G. & Nanda, R., 1996. An evaluation of root resorption incident to orthodontic intrusion. *American Journal of Orthodontics and Dentofacial Orthopedics* 109, pp. 543–548.
- Counts, A.L. & Widlak, R.A., 1993. Generalized idiopathic external root resorption. *Journal of Clinical Orthodontics* 27, pp. 511–513.
- Darendeliler, M.A., Kharbanda, O.P., Chan, E.K., et al., 2004. Root resorption and its association with alterations in physical properties, mineral contents and resorption craters in human premolars following application of light and heavy controlled orthodontic forces. *Orthodontics & Craniofacial Research* 7, pp. 79–97.
- Davidovitch, Z., Godwin, S.L., Park, Y.G., et al., 1996. The etiology of root resorption. In: McNamara, J.A., Trotman, C.A., eds. *Orthodontic treatment: the management of unfavorable sequelae*. Ann Arbor, MI: University of Michigan Press, pp. 93–117.
- Dermaut, L.R. & De Munck, A., 1986. Apical root resorption of upper incisors caused by intrusive tooth movement: a radiographic study. *American Journal of Orthodontics and Dentofacial Orthopedics* 90, pp. 321–326.
- DeShields, R.W., 1969. A study of root resorption in treated Class II, Division I malocclusions. *Angle Orthodontist* 39, pp. 231–245.
- Drysdale, C., Gibbs, S.L. & Ford, T.R., 1996. Orthodontic management of root-filled teeth. *British Journal of Orthodontics* 23, pp. 255–260.
- English, H., 2001. External apical root resorption as a consequence of orthodontic treatment. *Journal of New Zealand Society of Periodontology* 86, pp. 17–23.
- Faltin, R.M., Faltin, K., Sander, F.G. et al., 2001. Ultrastructure of cementum and periodontal ligament after continuous intrusion in humans: a transmission electron microscopy study. *European Journal of Orthodontics* 23, pp. 35–49.
- Fox, N., 2005. Longer orthodontic treatment may result in greater external apical root resorption. *Evidence-Based Dentistry* 6, p. 21.
- Fuss, Z., Tsesis, I. & Lin, S., 2003. Root resorption—diagnosis, classification and treatment choices based on stimulation factors. *Dental Traumatology* 19, pp. 175–182.
- Goldie, R.S. & King, G.J., 1984. Root resorption and tooth movement in orthodontically treated, calcium-deficient, and lactating rats. *American Journal of Orthodontics and Dentofacial Orthopedics* 85, pp. 424–430.
- Goldson, L. & Henrikson, C.O., 1975. Root resorption during Begg treatment: a longitudinal roentgenologic study. *American Journal of Orthodontics and Dentofacial Orthopedics* 68, pp. 55–66.
- Han, G., Huang, S., Von den Hoff, J.W. et al., 2005. Root resorption after orthodontic intrusion and extrusion: an intraindividual study. *Angle Orthodontist* 75, pp. 912–918.
- Hamilton, R.S. & Gutmann, J.L., 1999. Endodontic-orthodontic relationships: a review of integrated treatment planning challenges. *International Endodontic Journal* 32, pp. 343–360.

- Harris, D.A., Jones, A.S. & Darendeliler, M.A., 2006. Physical properties of root cementum: part 8. Volumetric analysis of root resorption craters after application of controlled intrusive light and heavy orthodontic forces: a microcomputed tomography scan study. *American Journal of Orthodontics and Dentofacial Orthopedics* 130, pp. 639–647.
- Harris, E.F. & Baker, W.C., 1990. Loss of root length and crestal bone height before and during treatment in adolescent and adult orthodontic patients. *American Journal of Orthodontics and Dentofacial Orthopedics* 98, 463–469.
- Harris, E.F., Kineret, S.E. & Tolley, E.A., 1997. A heritable component for external apical root resorption in patients treated orthodontically. *American Journal of Orthodontics and Dentofacial Orthopedics* 111, pp. 301–309.
- Harris, E.F., Robinson, Q.C. & Woods, M.A., 1993. An analysis of causes of apical root resorption in patients not treated orthodontically. *Quintessence International* 24, pp. 417–428.
- Harry, M.R. & Sims, M.R., 1982. Root resorption in bicuspid intrusion. A scanning electron microscope study. *Angle Orthodontist* 52, pp. 235–258.
- Hartsfield, J.K., Jr., Everett, E.T. & Al-Qawasmi, R.A., 2004. Genetic factors in external apical root resorption and orthodontic treatment. *Critical Reviews in Oral Biology Medicine* 15, pp. 115–122.
- Horiuchi, A., Hotokezaka, H. & Kobayashi, K., 1998. Correlation between cortical plate proximity and apical root resorption. *American Journal of Orthodontics and Dentofacial Orthopedics* 114, pp. 311–318.
- Igarashi, K., Adachi, H., Mitani, H. et al., 1996. Inhibitory effect of topical administration of a bisphosphonate (risedronate) on root resorption incident to orthodontic tooth movement in rats. *Journal of Dental Research* 75, pp. 1644–1649.
- Janson, G.R., De Luca Canto, G., Martins, D.R. et al. 1999. A radiographic comparison of apical root resorption after orthodontic treatment with 3 different fixed appliance techniques. *American Journal of Orthodontics and Dentofacial Orthopedics* 118, pp. 262–273.
- Jimenez-Pellegrin, C. & Arana-Chavez, V.E., 2004. Root resorption in human mandibular first premolars after rotation as detected by scanning electron microscopy. *American Journal of Orthodontics and Dentofacial Orthopedics* 126, pp. 178–184; discussion 184–185.
- Kaley, J. & Phillips, C., 1991. Factors related to root resorption in edgewise practice. *Angle Orthodontist* 61, pp. 125–132.
- Kalkwarf, K.L., Krejci, R.F. & Pao, Y.C., 1986. Effect of apical root resorption on periodontal support. *Journal of Prosthetic Dentistry* 56, pp. 317–319.
- Katona, T.R., 2006. Flaws in root resorption assessment algorithms: role of tooth shape. *American Journal of Orthodontics and Dentofacial Orthopedics* 130, pp. 698.e19–698.e27.
- Kennedy, D., Joondeph, D., Osterberg, S. et al., 1983. The effect of extraction and orthodontic treatment on dentoalveolar support. *American Journal of Orthodontics and Dentofacial Orthopedics* 84, pp. 183–190.
- Ketcham, A.H., 1927. A preliminary report of an investigation of apical root resorption of vital permanent teeth. *International Journal of Orthodontics* 13, 97–127.
- Killiany, D.M., 2002. Root resorption caused by orthodontic treatment: review of literature from 1998 to 2001 for evidence. *Progress in Orthodontics* 3, pp. 2–5.
- Kjaer, I., 1995. Morphological characteristics of dentitions developing excessive root resorption during orthodontic treatment. *European Journal of Orthodontics* 17 pp. 25–34.
- Konoo, T., Kim, Y.J., Gu, G.M. et al., 2001. Intermittent force in orthodontic tooth movement. *Journal of Dental Research* 80, pp. 457–460.
- Kook, Y-A., Park, S. & Sameshima, G.T., 2003. Peg-shaped and small lateral incisors not at higher risk for root resorption. *American Journal of Orthodontics and Dentofacial Orthopedics* 123, 253–258.
- Kurol, J. & Owman-Moll, P., 1998. Hyalinization and root resorption during early orthodontic tooth movement in adolescents. *Angle Orthodontist* 68, pp. 161–165.

- Lee, R.Y., Artun, J. & Alonzo, T.A., 1999. Are dental anomalies risk factors for apical root resorption in orthodontic patients? *American Journal of Orthodontics and Dentofacial Orthopedics* 116, pp. 187–195.
- Levander, E. & Malmgren, O., 1988. Evaluation of the risk of root resorption during orthodontic treatment: a study of upper incisors. *European Journal of Orthodontics* 10, pp. 30–38.
- Levander, E., Malmgren, O. & Eliasson, S., 1994. Evaluation of root resorption in relation to two orthodontic treatment regimes. A clinical experimental study. *European Journal of Orthodontics* 16, pp. 223–228.
- Levander, E. & Malmgren, O., 2000. Long-term follow-up of maxillary incisors with severe root resorption. *European Journal of Orthodontics* 22, pp. 85–92.
- Levander, E., Malmgren, O. & Stenback, K. 1998. Apical root resorption during orthodontic treatment of patients with multiple aplasia: a study of maxillary incisors. *European Journal of Orthodontics* 20, pp. 427–434.
- Lew, K., 1990. Intrusion and apical resorption of mandibular incisors in Begg treatment: anchorage bend or curve? *Australian Orthodontic Journal* 11, pp. 164–168.
- Linge, B.O. & Linge, L., 1983a. Root length of upper canines and orthodontic therapy. *Fortschr Kieferorthop* 5, pp. 392–407.
- Linge, B.O. & Linge, L., 1983b. Apical root resorption in upper anterior teeth. *European Journal of Orthodontics* 5, pp. 173–183.
- Linge, L. & Linge, B.O., 1991. Patient characteristics and treatment variables associated with apical root resorption during orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 99, pp. 35–43.
- Loberg, E.L. & Engstrom, C., 1994. Thyroid administration to reduce root resorption. *Angle Orthodontist* 64, pp. 395–399.
- Lupi, J.E., Handelman, C.S. & Sadowsky, C., 1996. Prevalence and severity of apical root resorption and alveolar bone loss in orthodontically treated adults. *American Journal of Orthodontics and Dentofacial Orthopedics* 109, pp. 28–37.
- Malmgren, O., Goldson, L., Hill, C. et al., 1982. Root resorption after orthodontic treatment of traumatized teeth. *American Journal of Orthodontics and Dentofacial Orthopedics* 82, pp. 487–491.
- Mandall, N., Lowe, C., Worthington, H. et al., 2006. Which orthodontic archwire sequence? A randomized clinical trial. *European Journal of Orthodontics* 28, pp. 561–566.
- Mavragani, M., Boe, O.E., Wisth, P.J. et al. 2002. Changes in root length during orthodontic treatment: advantages for immature teeth. *European Journal of Orthodontic* 24, pp. 91–97.
- McFadden, W.M., Engstrom, C., Engstrom, H. et al. 1989. A study of the relationship between incisor intrusion and root shortening. *American Journal of Orthodontics and Dentofacial Orthopedics* 96, pp. 390–396.
- McLaughlin, K.D., 1964. Quantitative determination of root resorption during orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 50, p. 143.
- McNab, S., Battistutta, D., Taverne, A. et al., 1999. External apical root resorption of posterior teeth in asthmatics after orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 116, pp. 545–551.
- McNab, S., Battistutta, D., Taverne, A. et al., 2000. External apical root resorption following orthodontic treatment. *Angle Orthodontist* 70, pp. 227–232.
- Midgett, R.J., Shaye, R. & Fruge, J.F., Jr., 1981. The effect of altered bone metabolism on orthodontic tooth movement. *American Journal of Orthodontics and Dentofacial Orthopedics* 80, pp. 256–262.
- Mirabella, A.D. & Artun, J., 1995. Risk factors for apical root resorption of maxillary anterior teeth in adult orthodontic patients. *American Journal of Orthodontics and Dentofacial Orthopedics* 108, pp. 48–55.
- Newman, W.G., 1975. Possible etiologic factors in external root resorption. *American Journal of Orthodontics and Dentofacial Orthopedics* 67, pp. 522–539.

- Ngan, D.C.S., Kharbanda, O.P., Byloff, F.K. et al., 2004. The genetic contribution to orthodontic root resorption: a retrospective twin study. *Australian Orthodontic Journal* 20, pp. 1–9.
- Otis, L., Hong, J. & Tuncay, O., 2004. Bone structure effect on root resorption. *Orthodontics & Craniofacial Research* 7, pp. 165–177.
- Owman-Moll, P. & Kurol, J., 1998. The early reparative process of orthodontically induced root resorption in adolescents—location and type of tissue. *European Journal of Orthodontics* 20, pp. 727–732.
- Owman-Moll, P., Kurol, J. & Lundgren, D., 1995. Continuous versus interrupted continuous orthodontic force related to early tooth movement and root resorption. *Angle Orthodontist* 65, pp. 395–401, discussion pp. 401–402.
- Owman-Moll, P., Kurol, J. & Lundgren, D., 1996a. Effects of a doubled orthodontic force magnitude on tooth movement and root resorptions. An intra-individual study in adolescents. *European Journal of Orthodontics* 18, pp. 141–150.
- Owman-Moll P., Kurol J. & Lundgren D., 1996b. The effects of a four-fold increased orthodontic force magnitude on tooth movement and root resorptions. An intra-individual study in adolescents. *European Journal of Orthodontics* 18, pp. 287–294.
- Parker, R.J. & Harris, E.F., 1998. Directions of orthodontic tooth movements associated with external apical root resorption of the maxillary central incisor. *American Journal of Orthodontics and Dentofacial Orthopedics* 114, pp. 672–683.
- Pandis, N., Nasika, M., Polychronopoulou, A. et al., 2008. External apical root resorption in patients treated with conventional and self-ligating brackets. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 646–651.
- Pizzo, G., Licata, M.E., Guiglia, R. et al., 2007. Root resorption and orthodontic treatment. Review of the literature. *Minerva Stomatologia* 56, pp. 31–44.
- Poumpros, E., Loberg, E. & Engstrom, C., 1994. Thyroid function and root resorption. *Angle Orthodontist* 64, pp. 389–393.
- Proffit, W.R., Fields, H.W. & Sarver, D.M., 2006. *Contemporary orthodontics*. 4th ed., St. Louis: CV Mosby.
- Reitan, K., 1974. Initial tissue behaviour during apical root resorption. *Angle Orthodontist* 44, pp. 68–82.
- Remington, D.N., Joondeph, D.R., Artun, J. et al., 1989. Long-term evaluation of root resorption occurring during orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 96, pp. 43–46.
- Reukers, E., Sanderink, G., Kuijpers-Jagtman, A.M. et al., 1998. Assessment of apical root resorption using digital reconstruction. *Dento-Maxillo-Facial Radiology* 27, pp. 25–29.
- Rivera, E.M. & Walton, R.E., 1994. Extensive idiopathic apical root resorption. A case report. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* 78, pp. 673–677.
- Rygh, P. & Reitan, K., 1972. Ultrastructural changes in the periodontal ligament incident to orthodontic tooth movement. *Transactions. European Orthodontic Society*, pp. 393–405.
- Sameshima, G.T. & Sinclair, P.M., 2001a. Predicting and preventing root resorption: Part I. Diagnostic factors. *American Journal of Orthodontics and Dentofacial Orthopedics* 119, pp. 505–510.
- Sameshima, G.T. & Sinclair, P.M., 2001b. Predicting and preventing root resorption: Part II. Treatment factors. *American Journal of Orthodontics and Dentofacial Orthopedics* 119, pp. 511–515.
- Sameshima, G.T. & Sinclair, P.M., 2004. Characteristics of patients with severe root resorption. *Orthodontics & Craniofacial Research* 7, pp. 108–114.
- Schwartz, A.M., 1932. Tissue changes incidental to tooth movement. *International Journal of Orthodontics* 96, pp. 331–352.
- Scott, P., DiBiase, A.T., Sherriff, M. et al., 2008. Alignment efficiency of Damon3 self-ligating and conventional orthodontic bracket systems: A randomized clinical trial. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 470.e1–470.e8.

- Segal, G., Schiffman, P. & Tuncay, O., 2004. Meta analysis of the treatment-related factors of external apical root resorption. *Orthodontics & Craniofacial Research* 7, pp. 71–78.
- Shirazi, M., Dehpour, A.R. & Jefari, F., 1999. The effect of thyroid hormone on orthodontic tooth movement in rats. *Journal of Clinical Pediatric Dentistry* 23, pp. 259–264.
- Smale, I., Artun, J., Behbehani, F. et al., 2005. Apical root resorption 6 months after initiation of fixed orthodontic appliance therapy. *American Journal of Orthodontics and Dentofacial Orthopedics* 128, pp. 57–67.
- Snelgrove, R.A., 1995. Generalized idiopathic apical root resorption as an incidental finding in an adolescent: A case history. *Dental Update* 22, pp. 276–278.
- Spurrier, S.W., Hall, S.H. & Joondeph, D.R., 1990. A comparison of apical root resorption during orthodontic treatment in endodontically treated and vital teeth. *American Journal of Orthodontics and Dentofacial Orthopedics* 97, pp. 130–134.
- Stevnik, A. & Mjor, I.A., 1970. Pulp and dentine reactions to experimental tooth intrusion. A histological study of the initial changes. *American Journal of Orthodontics and Dentofacial Orthopedics* 57, pp. 370–385.
- Taithongchai, R., Sookkorn, K. & Killiany, D.M., 1996. Facial and dentoalveolar structure and the prediction of apical root shortening. *American Journal of Orthodontics and Dentofacial Orthopedics* 110, pp. 311–320.
- Taner, T., Ciger, S. & Sencift, Y., 1999. Evaluation of apical root resorption following extraction therapy in subjects with class I and class II malocclusions. *European Journal of Orthodontics* 21, pp. 491–496.
- TenHoeve, A. & Mulie, R.M., 1976. The effects of antero-postero incisor repositioning on the palatal cortex as studied with laminagraphy. *Journal of Clinical Orthodontics* 10, pp. 804–822.
- Thongudomporn, U. & Freer, T.J., 1998. Anomalous dental morphology and root resorption during orthodontic treatment: a pilot study. *Australian Orthodontic Journal* 15, pp. 162–167.
- Trope, M., 1998. Root resorption of dental traumatic origin: classification based on etiology. *Practical Periodonics and Aesthetetic Dentistry* 10, pp. 515–522.
- Villa, P.A., Oberti, G., Moncada, C.A. et al., 2005. Pulp-dentine complex changes and root resorption during intrusive orthodontic tooth movement in patients prescribed nabumetone. *Journal of Endodontics* 31, pp. 61–66.
- Weiland, F., 2003. Constant versus dissipating forces in orthodontics: the effect on initial tooth movement and root resorption. *European Journal of Orthodontics* 25, pp. 335–342.
- Weltman, B.J., Vig, K.W.L., Fields, H.W. et al., 2010. Root resorption associated with orthodontic tooth movement: a systematic review. *American Journal of Orthodontics and Dentofacial Orthopedics* 137, pp. 462–476.
- Wickwire, N.A., Mc Neil, M.H., Norton, L.A. et al., 1974. The effects of tooth movement upon endodontically treated teeth. *Angle Orthodontist* 44, pp. 235–242.

6

Malocclusion, Orthodontic Treatment, and Periodontal Health—An Assessment of the Evidence

Anne-Marie Bollen, DDS, MS, PhD

Professor of Orthodontics, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Washington

Background and Etiology

One of the rationales often used to promote orthodontic treatment is that it will prevent periodontal problems. This rationale is based on the reasoning that a malocclusion may cause periodontal problems, and therefore, by treating the malocclusion, we can prevent the periodontal deterioration. There are several issues related to this argument that need to be considered.

First, what is a malocclusion? The term “malocclusion” implies a negative or harmful condition. However, malocclusions should not be considered a disease or a biological abnormal state (Vig & Dryland Vig 1995), even though the term includes the prefix “mal.” For an orthodontist, a malocclusion usually means any condition with malaligned teeth, or the lack of a “proper” occlusion, which is most often defined as a Class I interdigitation with an “ideal” overjet in the sagittal direction, no crossbites or scissors bites

in the transverse direction, and about a 2-mm positive overbite in the vertical dimension. Deviations from this often result in a recommendation for treatment without considering if a correction is actually needed, wanted, and/or beneficial. From the perspective of patients, malocclusions are usually conditions with less than acceptable esthetic appeal. Orthodontists quite often are happy to “educate” prospective patients, and the belief that a less than ideal “bite” may result in periodontal problems is often used during these discussions.

Second, what is the evidence that a malocclusion is causing periodontal disease? To unequivocally establish the existence of true cause and effect, one should embark on a randomized controlled study, in which malocclusions are randomly assigned to participants and their effects on periodontal condition are measured. No such studies are available. Several studies with lower levels of evidence (epidemiological surveys, cross-sectional and cohort studies) have evaluated the coexistence of malocclusions and periodontal disease (see below). However, both conditions are very prevalent, and their simultaneous occurrence does not prove cause and effect.

Lastly, does orthodontic treatment reduce the risk for periodontal disease? The strongest evidence that orthodontic treatment prevents periodontal problems comes from studies that directly measure the effects of this treatment on periodontal health, not by relying on the assumption that the elimination of malocclusions has to be beneficial. Several studies have compared the periodontal health between individuals with or without orthodontic treatment. The results have been evaluated in systematic reviews. So far, these studies have failed to indicate a positive effect of orthodontic treatment on periodontal health.

Prevalence

Periodontal Disease

Periodontal disease is common. It has been reported that more than 50% of the dentate U.S. population aged 30 to 90 have attachment loss greater than 3 mm, and more than 60% have probing depths equal to or greater than 3 mm (Albandar, Brunelle & Kingman 1999). With increasing age, the prevalence of all periodontal problems increases.

Malocclusion

Data from the third National Health and Nutrition Examination Survey indicate that 20% of the population have deviations from the ideal occlusal relationships, and only 35% of the of adults have well-aligned mandibular incisors (Proffit et al. 1998).

Orthodontic Treatment

In the United States it is estimated that about 30% of the population receives orthodontic treatment (Bollen, Cunha-Cruz & Hujoel 2007). This varies depending on socioeconomic status and race (Proffit, Fields & Moray 1998; Bollen, Cunha-Cruz & Hujoel 2007). A survey by the American Association of Orthodontics reported 5.75 million patients in orthodontic treatment in 2004 (American Association of Orthodontics 2005).

Evidence on the Relationship Between Malocclusion and Periodontal Health

The association between occlusal forces and periodontal destruction is an ongoing controversial issue, as recent publications attest (Deas & Mealey 2006). If the relationship between occlusal forces and periodontal conditions is uncertain, it shouldn't be surprising that the relationship between malocclusions and periodontal health is even more dubious (with "malocclusions" denoting the conditions usually recognized by orthodontists as needing orthodontic corrections, such as crowding, open or deep bites, crossbites, and overjet). However, the amount of studies in this area is vast, and several review articles and systematic reviews have been conducted.

One systematic review evaluated the relationship between periodontal health and malocclusions where "malocclusions" were recorded using any malocclusion index (Bollen 2008). Because most malocclusion indices combine various components of the dental alignment and occlusion (such as crowding, overjet, etc.), it was thought that this would be a better representation of the majority of patients who usually have several deviant occlusal traits making up their malocclusion. Studies included were limited to humans and excluded those related to individuals with disabilities or specific syndromes. The exposure was malocclusion index, excluding studies evaluating occlusal interferences, balancing contacts, or parafunctions. Studies were included only if there was a control group (either a comparison group of individuals without a malocclusion or a lower severity/grade of the malocclusion). The outcome was any periodontal condition.

The electronic search criteria included malocclusion and periodontal terms and covered publications from 1960 through 2006 on Medline, Web of Science, Cochrane Library, and the gray literature, with no exclusion based on language.

The electronic search identified 2646 unique publications. Titles and abstracts (when available) were screened, and a total of 97 full publications were retrieved for review. These full articles were read, and 72 papers were excluded because they did not fulfill the search criteria. This left a total of 25 studies that reported on 35,300 subjects with a mean age of 22 (range 3 to 60). One cohort study, two case-control studies, and 22 cross-sectional studies reported on a variety of malocclusion indices, ranging from commonly used indices (such as the Occlusion Feature Index and the Dental Aesthetic Index) to custom-designed indices based on overjet/crowding and other malocclusion aspects. The outcome measures ranged from periodontitis, to various periodontal disease indices, to tooth loss. Five of the 25 studies adjusted for possible confounding variables (such as age, socioeconomic status, and/or oral hygiene). The great variability in exposure and outcome variables made it difficult to perform data extraction. However, it was possible to combine data from some of the studies. Six studies (Geiger et al. 1972; Kalamparov, Gantsev & Ershov 1972; Onyeaso, Arowojolu & Taiwo 2003; Sergl & Krause 1973; Schneider & Brendel 1981; Shinberg, Saakian & Zapashnik 1991) contained data on malocclusion and "periodontopathies." Data extraction indicated that significantly greater periodontal problems were found in subjects with malocclusions compared to subjects without malocclusions ($p < 0.00001$). None of the included studies adjusted for confounding variables. Two studies on the interaction between malocclusion and gingivitis (McCombie & Stothard 1964; Miller & Hobson 1961) found greater levels of gingivitis in subjects with

a malocclusion compared to those without a malocclusion ($p < 0.0001$). One of these studies (Miller & Hobson 1961) adjusted for oral hygiene.

In summary, there is evidence that subjects with malocclusions have less-healthy periodontal conditions than subjects with less severe malocclusions or with no malocclusion. However, the lack of adjustment for confounding variables in most of these studies, reduces the confidence of this finding. Studies adjusting for oral hygiene often do not find a correlation between malocclusions and periodontal health. Also, the presence of a correlation between the two entities does not prove cause and effect.

Evidence on the Relationship Between Orthodontic Treatment and Periodontal Health

A systematic review of the relationship between orthodontic treatment and periodontal health was published recently (Bollen et al. 2008). This systematic review confirmed the results reported in two other previous reviews (Burden 2007; van Gastel et al. 2007). The most recent systematic review (Bollen et al. 2008) included only studies in which patients who received orthodontic treatment were compared with a control group with no orthodontic treatment. Randomized controlled trials (RCTs), cohort studies, case-control, and cross-sectional studies were evaluated. Only studies of humans were included, with no restriction in patient's age or type of malocclusion; studies of patients with severe periodontal disease or craniofacial anomalies were excluded. Studies of contemporary orthodontic treatment with fixed or removable appliances were included; treatment with fully banded appliances or with orthognatic surgery or distraction osteogenesis were excluded. Studies had to report on at least one periodontal outcome after the removal of orthodontic appliances.

Electronic searches in eight databases (1980–2006), bibliographic reference listings, and hand searches in six journals (1980–2006) were performed. Methodological quality was assessed for each of the included studies using the Newcastle-Ottawa Quality Assessment Scale. Data extraction was performed for some of the outcomes, and summary estimates were presented if the statistical heterogeneity levels were less than 70%.

The electronic searches retrieved 3552 unique citations. After evaluating the titles and abstracts of all citations and the full text of 104 citations, 14 studies remained that met the inclusion criteria. Of these, one article was excluded because it was a duplicate study, and two articles were excluded because of the absence of statistics. During the hand searching, 20,551 full-text reports were coded. Of these, 214 were studies involving humans, reporting on orthodontic treatment and a periodontal outcome. Of these, 9 met the inclusion criteria. Only one of these studies was different from those retrieved with the electronic search. Thus a total of 12 papers were included in the review.

Of the included studies, one was an RCT, three were prospective cohort studies, and eight were cross-sectional studies. These studies reported on a total of 821 patients who had received orthodontic treatment for a variety of malocclusions and 849 who comprised the untreated control group. The participants' ages ranged from 12 to 47 years old. Due to the wide diversity of periodontal outcomes measured, it was possible to extract data for only three periodontal conditions.

Data on alveolar bone loss were obtained from three studies (Ogaard 1988; Bondemark 1998; Janson et al. 2003). Patients with prior orthodontic treatment had 0.13 mm greater alveolar bone loss than patients without prior orthodontic treatment (range 0.07–0.20; $p = 0.0001$).

Data on periodontal pocket depth were obtained from two studies (Janson 1984; Ribeiral, Bolognese & Feres 1999), and they indicated 0.23 mm greater pocket depth in subjects with prior orthodontic treatment (range 0.15–0.3; $p = 0.00001$). Data on gingival recession were retrieved from three studies (Ribeiral, Bolognese & Feres 1999; Thomson 2002; Allais & Melsen 2003) and indicated 0.03 mm greater recession in subjects with prior orthodontic treatment (range 0.01–0.04; $p = 0.0001$).

This systematic review failed to find a beneficial effect of orthodontic treatment on periodontal health. On the contrary, patients with prior orthodontic care had greater alveolar bone loss, periodontal pocket depth, and gingival recession than individuals who had not received orthodontic treatment.

The weaknesses of the systematic review were the lack of good quality studies with high levels of evidence. Also, the reported differences were posttreatment differences. There was a lack of information on the pretreatment periodontal status. The reported small worsening of the periodontal conditions after orthodontic treatment is a generalized mean for the entire dentition. This small (yet significant) difference may be of clinical importance if it is a localized effect (a large worsening around a few teeth) rather than a generalized effect (small worsening around all teeth). Also, the majority of the studies focused on common orthodontic care in the adolescent population. There were no studies that evaluated the effects on the periodontium of some very specific types of treatment. For example, orthodontic correction of an anterior crossbite may improve the periodontal condition of the mandibular incisors (Figure 6.1).

This systematic review confirmed the results reported in two other previous reviews (Burden 2007; van Gastel et al. 2007). Since the above reviews were published, other studies have reported on the relationship between orthodontic treatment and periodontal health. Of particular interest is the paper by Slutzkey & Levin (2008). This study evaluated a cohort of 303 healthy patients who had routine dental examinations at a military dental center. It found increased recession in young adults who had undergone orthodontic treatment (on average 4.8 years prior) compared to those who did not have orthodontic treatment. Also, the severity and the extent of the recession were significantly correlated with past orthodontic treatment. No correlation between recession and gingivitis was found, and individuals with better oral hygiene had greater recession. This study supports the findings of the systematic reviews: orthodontic treatment does not improve periodontal health (gingival recession), and it may actually make it worse. It also seems that the increase in recession is localized on a few teeth rather than a generalized small amount of recession for a large number of teeth. This is of greater clinical importance.

Future Directions

There is weak evidence that orthodontic treatment may not contribute to a healthier periodontium due to a lack of high-quality randomized clinical trials. Future well-designed, high-quality studies may provide greater evidence for the long-term effects of orthodontic treatment on periodontal health.



A



B

Figure 6.1 (A) Anterior crossbite with mobility and recession on the mandibular left central incisor. (B) Spontaneous reduction of the recession and mobility (and improved alignment) of the mandibular left central incisor after correction of the crossbite with maxillary fixed appliances (without any orthodontic treatment of the mandibular arch).

While the current evidence may be weak, it does seem to consistently indicate a lack of positive effects of orthodontic treatment on average periodontal health. However, this applies to orthodontic treatment in general and may not relate to the treatment of some very specific malocclusions (such as anterior crossbites with lower incisor mobility and recession). In the absence of such specific detrimental conditions, it would be prudent to refrain from promoting orthodontic treatment for the prevention of future periodontal problems.

Acknowledgments

This project was supported by grants from the ADA Foundation and the National Institute of Dental and Craniofacial Research of the National Institutes of Health.

References

- Albandar, J.M., Brunelle, J.A. & Kingman, A. 1999. Destructive periodontal disease in adults 30 years of age and older in the United States, 1988–1994. *Journal of Periodontology* 70, pp. 13–29.
- Allais, D. & Melsen, B., 2003. Does labial movement of the lower incisors influence the level of the gingival margin? A case-control study of adult orthodontic patients. *European Journal of Orthodontics* 25, pp. 343–352.
- American Association of Orthodontics, 2005. AAO tracks trends, patient data through 2004 Patient & Member Census Study. *The Bulletin* 23, p. 4.
- Bollen, A.-M., 2008. Effects of malocclusions and orthodontics on periodontal health: evidence from a systematic review. *Journal of Dental Education* 72, pp. 912–918.
- Bollen, A.-M., Cunha-Cruz, J., Bakko, D.W. et al., 2008. Effects of orthodontic therapy on periodontal health; a systematic review of controlled evidence. *Journal of the American Dental Association* 139, pp. 413–422.
- Bollen, A.-M., Cunha-Cruz, J. & Hujoel, P.P., 2007. Secular trends in US pre-adult orthodontic care: 1942–2002. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 579–585.
- Bondemark, L., 1998. Interdental bone changes after orthodontic treatment: a 5-year longitudinal study. *American Journal of Orthodontics and Dentofacial Orthopedics* 114, pp. 25–31.
- Burden, D.J., 2007. Oral health-related benefits of orthodontic treatment. *Seminars in Orthodontics* 13, pp. 76–80.
- Deas, D.E. & Mealey, B.L., 2006. Is there an association between occlusion and periodontal destruction? Only in limited circumstances does occlusal force contribute to periodontal disease progression. *Journal of the American Dental Association* 137, pp. 1381–1389.
- Geiger, A.M., Wasserman, B.H., Thompson, R.H., Jr. et al., 1972. Relationship of occlusion and periodontal disease. V. Relationship of classification of occlusion to periodontal status and gingival inflammation. *Journal of Periodontology* 43, pp. 554–560.
- Janson, G., Bombonatti, R., Brandao, A.G. et al., 2003. Comparative radiographic evaluation of the alveolar bone crest after orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 157–164.
- Janson, M., 1984. Gingival and periodontal relationships after orthodontic therapy: a study of Class II patients. *Deutsche zahnärztliche Zeitschrift* 39, pp. 254–256 (In German).
- Kalamparov, K., Gantsev, G.A. & Ershov, V.N., 1972. Relationship between dentomaxillary deformities and periodontal diseases in children. *Stomatologiya (Mosk)* 51, pp. 47–50.
- McCombie, F. & Stothard, D., 1964. Relationships between gingivitis and other dental conditions. *Journal of the Canadian Dental Association* 30, pp. 506–513.
- Miller, J. & Hobson, P., 1961. The relationship between malocclusion, oral cleanliness, gingival conditions, and dental caries in school children. *British Dental Journal* 111, pp. 43–52.
- Ogaard, B., 1988. Marginal bone support and tooth lengths in 19-year-olds following orthodontic treatment. *European Journal of Orthodontics* 10, pp. 180–186.
- Onyeaso, C.O., Arowojolu, M.O. & Taiwo, J.O., 2003. Oral hygiene status and occlusal characteristics of orthodontic patients at University College Hospital, Ibadan, Nigeria. *Odontostomatol Tropica* 26, pp. 24–28.

- Proffit, W.R., Fields, H.W. & Moray, L.J., 1998. Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey. *International Journal of Adult Orthodontics and Orthognatic Surgery* 13, pp. 97–106.
- Ribeiral, M.B.C., Bolognese, A.M. & Feres, E.J., 1999. Periodontal evaluation after orthodontic treatment (abstract A-148). *Journal of Dental Research* 78, p. 979.
- Sergl, H.G. & Krause, H., 1973. Studies on the effects of malocclusions on the periodontium. *Deutsche zahnärztliche Zeitschrift* 28, pp. 149–154.
- Schneider, H.G. & Brendel, A.K., 1981. Oral hygiene study of children under orthodontic treatment. *Stomatologie der DDR* 31, pp. 258–264.
- Shinberg, O.E., Saakian, S. & Zapashnik, E.K., 1991. The functional periodontal overload in bite anomalies in adults. *Stomatologiya (Mosk)* 6, pp. 42–44.
- Slutzkey, S. & Levin, L., 2008. Gingival recession in young adults: occurrence, severity, and relationship to past orthodontic treatment and oral piercing. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 652–656.
- Thomson, W.M., 2002. Orthodontic treatment outcomes in the long term: findings from a longitudinal study of New Zealanders. *Angle Orthodontist* 72, pp. 449–455.
- Van Gastel, J., Quirynen, M., Teughels, W. et al., 2007. The relationships between malocclusion, fixed orthodontic appliances and periodontal disease. A review of the literature. *Australian Orthodontic Journal* 23, pp. 121–129.
- Vig, P.S. & Vig, K., 1995. Decision analysis to optimize the outcomes for Class II division 1 orthodontic treatment. *Seminars in Orthodontics* 1, pp. 139–148.

Stability of Anterior Open Bite Correction—An Assessment of the Evidence

Greg J. Huang¹, DMD, MSD, MPH, **Geoffrey M. Greenlee²**, DDS, MSD, MPH

¹Associate Professor and Chair, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Washington

²Clinical Assistant Professor, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Washington

Background and Etiology of Open Bite

Ask any orthodontist what types of malocclusions are the most challenging to treat and anterior open bite is among those at the top of the list. The following examples illustrate the clinical range and complexity of open bite malocclusions (Figure 7.1). Not only is treatment difficult, retention can be even more challenging. This chapter will attempt to compile information on suspected etiologies of anterior open bite, the prevalence in various populations, and strategies that have been employed to treat open bite malocclusions. Additionally, the evidence on long-term stability after orthodontic treatment will be assessed. Finally, new techniques and strategies for addressing open bite malocclusions will be discussed.

It may be helpful to propose some definitions. One clinical definition of anterior open bite may be the lack of incisor contact in centric occlusion. Another may be the lack of incisor overlap, as measured relative to a defined plane, such as the occlusal plane.



Figure 7.1 Three examples of open bite malocclusion.

Cephalometrically, the use of a reference plane to measure vertical relationships of the incisors seems reasonable, and several have been used. The occlusal plane is commonly employed as a reference, as are perpendicular lines to Frankfort horizontal and sella-nasion (or derivatives of sella-nasion). Another commonly used reference line is nasion-menton. Regardless of the reference line that is used, some factors to consider for cephalometric measurement are reliability in identifying the points that establish the plane of reference, reasonable geometric relationships to the measurement of interest, and stability of the reference plane over time. The definition of open bite and the measurement method employed can influence prevalence, diagnosis, success, and long-term stability. For the purposes of this chapter, an open bite tendency describes an anterior tooth relationship that does not display incisor contact but does have some vertical overlap of the incisors. Patients with open bite tendencies can often bring their incisors into contact on protrusion (Figure 7.2A). The true anterior open bite designation will be reserved for those individuals who have no vertical overlap of the incisors, as measured via a reference line such as occlusal plane or Nasion-Menton (Figure 7.2B). Distinction is sometimes made between dental and skeletal open bites:

- Dental open bites display normal skeletal relationships, with the open bite primarily due to vertical displacement of the incisors.

- Skeletal open bites are characterized by steep mandibular planes, divergent facial patterns (increased anterior facial height, shortened posterior facial height), and antegonial notching (Cangialosi 1984; Sassouni 1969).

Although the etiology of open bite is often difficult to confirm, many factors have been implicated. For example, various digit, lip, and other oral habits have been reported in the literature (Subtelny & Sakuda 1964; Swineheart 1942; Popovich & Thompson 1973). Some habits involve tongue function and/or posture (Swineheart 1942; Rogers 1927; Straub 1960, 1961, 1962). Historically, tongue thrusting during swallowing has been considered as a cause of open bites. Experiments by Proffit demonstrated that although forces from the tongue during swallowing are significant in magnitude, the duration of these forces is probably insufficient to cause anterior open bite (Proffit 1978). A large tongue, or a tongue that is habitually postured between the incisors, is another commonly cited etiologic factor. There does appear to be some literature that supports this theory, as therapies that address tongue posture appear to result in fairly good long-term stability (Justus 1976; Huang et al. 1990). Additionally, glossotomies for patients with macroglossia have been reported to assist in closing open bites (Kawakami et al. 2005; Hotokezaka et al. 2001; Ball & Horrocks 1995; Ruff 1985). Prolonged pacifier use has also been found to be related to an increased incidence of anterior open bite (Gois et al. 2008; Verrastro et al. 2007; Warren et al. 2005; Adair et al. 1995). Obviously, discontinuing these habits, if possible, is the first step in trying to address the open bite.

It is commonly asked if open bites cause behaviors such as altered swallowing and speech or if these altered behaviors result in or perpetuate open bites. This “chicken or the egg” dilemma is difficult to answer with the existing literature. In past decades, speech and tongue function have been implicated as etiologic factors, and speech and myofunctional therapy have been recommended as treatments for open bite (Mason 2008; Haruki, Kishi & Zimmerman 1999; Benkert 1997; Zimmerman 1989; Garliner & Gables 1982). However, the scientific evidence on the success rate and long-term benefits of these therapies is lacking.

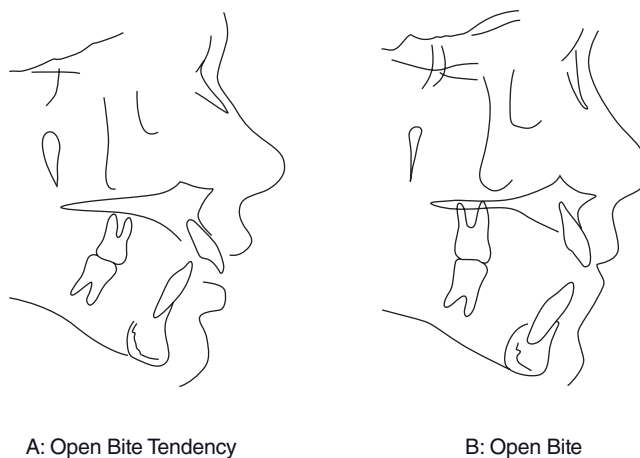


Figure 7.2 Open bite tendency (A) and open bite (B).

Airway has also been thought to be a contributor to anterior open bite, specifically in those whose primary mode of respiration is by mouth. Many investigators have studied the relationship between mouth breathing and anterior open bite in animal and human studies (Linder-Aronson 1970; Mahony, Karsten & Linder-Aronson 2004; Bresolin et al. 1983; Sassouni et al. 1985; Soukiet et al. 2009). There do appear to be some relationships, but these correlations are not always consistent(Fields et al. 1991; Vig KW. 1998).

Another causative factor may be genetics, which encompasses several entities. For example, unfavorable growth patterns have also been described as being associated with open bite (Sassouni 1969; Subtelny & Sakuda 1964; Schudy 1965; Bjork 1969). Many open bite patients do have divergent facial patterns and/or long faces. Also, patients with open bite have been reported to have weak musculature, which could be classified under genetic influence (Bakke & Michler 1991).

Sometimes patients are born with or develop neurological or neuromuscular deficits that can influence facial growth patterns and the vertical relationships of the teeth. For example, it is not uncommon that subjects with cerebral palsy or other developmental disabilities exhibit open bite (Asdaghi Mamaghani, Bode & Ehmer 2008; Carmagnani et al. 2007; Vittek et al. 1994). Likewise, patients affected by muscular dystrophy often have a higher occurrence of open bite (Ghafari et al. 1988; Kiliaridis, Mejersjo & Thilander 1989; Erturk & Dogan 1991; Morel-Verdebout, Botteron & Kiliaridis 2007).

Changes to the morphology of the condyle may also result in open bite. These changes may be sudden, as occurs in traumatic injuries, or progressive, as in idiopathic condylar resorption, arthritic processes, or avascular necrosis of the condyle (Hoppenreijs et al. 1998a). In any case, the usual result is a shortening of the posterior facial height, causing a clockwise rotation of the mandible around the molars, which act as a fulcrum, as the muscles of mastication elevate the ramus superiorly.

A careful diagnosis should be made to determine the possible cause of each patient’s open bite. If the etiologic factor can be identified and addressed, orthodontic treatment should have a higher chance for stability in the vertical dimension. If identification of the etiologic factor is ignored, stability will be unpredictable.

Prevalence of Open Bite

Several papers report on the prevalence of open bite, and prevalence appears to be related to various factors, such as age and race. The best data in the United States comes from the U.S. Health and Vital Statistics (Kelly, Sanchez & Kirk 1973; Kelly & Harvey 1977) and from NHANES III (Brunelle, Bhat & Lipton 1996). These surveys from the early 70s and early 90s, respectively, report on the prevalence of open bite among different races and age ranges.

Table 7.1 Open bite prevalence (2 mm or more).

6 to 11 Years Old		12 to 17 Years Old	
Caucasian	African American	Caucasian	African American
1.4%	9.6%	1.2%	10.1%

Sample consisted of 8000 subjects in each age range.
Data from: U.S. Health and Vital Statistics, 1973–1974.

Table 7.2 Distribution of subjects with open bite.

	8–11	12–17	18–50
0 to –2 mm	2.7%	2.8%	2.7%
–3 to –4 mm	0.6%	0.5%	0.5%
<–4 mm	0.3%	0.2%	0.1%

Sample consisted of 14,000 subjects, weighted to represent the population of Caucasian, African American, and Hispanic citizens of the United States.
Data from: NHANES III, 1989–1994.

Table 7.3 Open bite classification by age category.

Age	Open Bite (<i>n</i>)	Total (<i>n</i>)	Percentage (%)
7–9	20	148	13.5
10–12	9	243	3.7
13–15	21	275	7.6
16–18	40	403	9.9
19–21	14	215	6.5

Data from: Worms, Meskin & Isaacson (1971).

Interestingly, there is considerable variation by race. Within each race, the prevalence is quite stable over the various age categories. These findings lead us to wonder how many of these open bite subjects are getting treatment and how often treatment leads to stable results.

A question that commonly arises is “how often do open bites spontaneously correct?” Several studies have addressed this question with cross-sectional data. Perhaps the most commonly cited one is a cross-sectional study conducted by Worms and colleagues (1971). He classified open bites into three categories: (1) pseudo-open bite—those with no incisor contact but positive overlap; (2) simple open bite—those with no overlap from canine to canine; and compound open bite—indicating open bite from premolar to premolar. Using Worm’s data for the simple and compound open bites, whose definitions are consistent with the classification of “true” open bites illustrated in Figure 7.2B, we can calculate the rates of open bite subjects in the sample that Worms analyzed (Table 7.3). Although this study has commonly been cited as reporting an 80% spontaneous correction of simple open bite from the 7–9 age range to the 10–12 age range, it is rarely reported that the data also seem to indicate a doubling of the rate of open bite in the next age range. The variability of the data, relatively small samples in each age range, and cross-sectional nature of this study are all reasons to view these data cautiously.

It is difficult to collect longitudinal data on spontaneous closure of open bite in the United States, as orthodontists almost always recommend treatment when it is recognized. However, there are two small samples of untreated open bite that have been reported in the literature. The first comes from a randomized trial of 146 mixed dentition patients in Washington state, half of whom received interceptive orthodontic treatment and half of

whom received observation only. Of the 14 patients that had no incisor overlap and underwent 2 years of observation only, 6 (43%) displayed spontaneous correction after 2 years (Jolley et al. 2010). Another report from Brazil reported on 30 untreated open bite subjects, with a mean age slightly over 8 years (Pedrin et al. 2006). They reported that 4 (13%) exhibited spontaneous closure during the observation period, which lasted 1 year. The corresponding 30 subjects that underwent crib and chin cup therapy had an 80% closure rate in the same time period.

The data presented above seem to suggest a wide variation in the rate of spontaneous closure, and the evidence, at this time, is not conclusive. Data from the two large national surveys (cross-sectional) seem to indicate little change in open bite prevalence across age groups. Finally, data from two, small longitudinal studies seem to indicate that there may be some of spontaneous closure (13% to 40%) in the mixed dentition.

Treatment Options for Open Bite

Primary or Early Mixed Dentition

When open bites are discovered early, they are often accompanied by digit habits. Sometimes children may be very motivated to stop digit habits, and a candid discussion with their orthodontist may be sufficient to arrest the habit. Orthodontists may allow 3 to 6 months for children under 7 to attempt self-correction with simple therapies such as a mitten or glove worn at night, bitter compounds applied to the thumb, or thumb guards. If these are not sufficient, a thumb crib could be considered as a reminder. Although these are not particularly popular appliances to wear, acceptance is usually good if patients have already attempted simpler therapies without success. A common thought is that stopping a thumb or digit habit before the eruption of the permanent teeth usually results in spontaneous correction of the open bite and no long-term detrimental incisor relationships. However, every experienced orthodontist has probably seen a few patients stop their thumb habits early but still demonstrate persistence of an open bite as the permanent incisors erupt.

Late Mixed Dentition

By this time, most thumb and digit habits have stopped, and open bites persisting into this age group may be due to other factors, such as tongue posture or airway problems. Tongue posture is a commonly suspected etiologic factor, and late mixed dentition is usually a good time to recommend a tongue crib for correction of this problem. Two studies have suggested that tongue cribs lead to a high percentage of successful long-term closure of open bites (Justus 1976; Huang et al. 1990). A typical response to crib therapy is illustrated in Figure 7.3. Myofunctional therapy has been proposed as a means to modify aberrant tongue function and/or speech. However, the literature on the long-term success of myofunctional therapy is sparse (Mason 2008; Haruki, Kishi & Zimmerman 1999; Benkert 1997; Zimmerman 1989; Garliner & Gables 1982). Airway problems such as mouth breathing and enlarged tonsils have also been implicated in open bites, and tonsillectomy has been prescribed as a therapy. Extensive studies have been conducted on this issue, but no consistent etiologic relationships have been demonstrated (Linder-Aronson 1970;

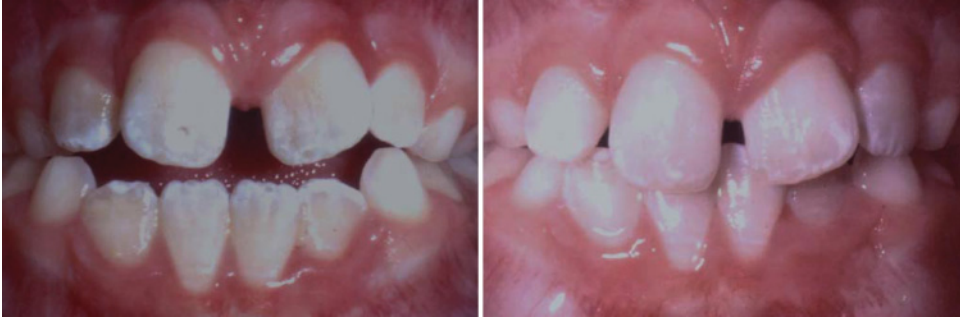


Figure 7.3 Nine months of crib use in a mixed dentition patient.

Mahony, Karsten & Linder-Aronson 2004; Bresolin et al. 1983; Sassouni et al. 1985; Soukiet et al. 2009; Fields et al. 1991; Vig KW. 1998). Other therapies that have been proposed in this developmental stage, including vertical elastics, posterior biteplates, magnets to intrude posterior teeth, chin cups to influence anterior vertical dimensions, spurs bonded to the incisors, jaw exercises, and low-seated transpalatal arches.

Permanent Dentition—Adolescent

In this developmental stage, conventional orthodontic treatment is commonly attempted for open bite patients. Correction of open bites using brackets and bands results primarily in dentoalveolar changes. For example, the multiloop edgewise (MEAW) technique closes open bites by dentoalveolar compensation (Kim et al. 2000). There is some support that extraction therapy may have a higher degree of long-term success compared to nonextraction therapy (Janson et al. 2006). The authors suggest that extraction therapy is more advantageous with respect to retracting incisors, thus encouraging deepening of the bite. During this time, growth modification is also possible, and many devices that target growth have been proposed, including high-pull headgear, chin cups, and functional appliances. The success of these devices long term is not well documented in the literature. In cases where the tongue is obviously in a forward position, tongue cribs may be prescribed. Again, if the etiologic agent can be identified prior to treatment and then addressed during treatment, the chance for success is probably increased.

Permanent Dentition—Adult

In nongrowing individuals with moderate to severe open bites, orthodontists may often consider surgery as the most appropriate and stable method to correct an open bite. The most common surgical procedure is LeFort I maxillary impaction with clockwise rotation, with concomitant mandibular surgery as needed for anteroposterior correction. Other types of surgery have been recommended, such as the Schuchart procedure (Ermel et al. 1999), which impacts the maxillary buccal segments, or bilateral sagittal split osteotomy with counterclockwise rotation (Bisase, Johnson & Stacey 2009). A surgical procedure that is rarely recommended is glossotomy. It may seem reasonable in patients who have unusually large tongues, and there are some reports of successful correction of open bite

after glossotomy in the dental literature (Kawakami et al. 2005; Hotokezaka et al. 2001; Ball & Horrocks 1995; Ruff 1985). Some orthodontists may also consider conventional orthodontic treatment for mild open bites or for patients who may not be concerned about the lack of incisal contact. Some recent suggestions for treatment of open bite include temporary anchorage devices (Seres & Kocsis 2009; Sakai et al. 2008; Sherwood 2007; Kuroda et al. 2007; Kravitz & Kusnoto 2007; Xun, Zeng & Wang 2007; Kuroda, Katayama & Takano-Yamamoto 2004; Erverdi, Keles & Nanda 2004; Umemori et al. 1999), corticotomy (Akay et al. 2009), and occlusal equilibration (Janson et al. 2008).

Impact of Severity and Growth Status

For many malocclusions, the severity of the problem, as well as the growth status of a patient, may influence an orthodontist's choice of treatment. This is certainly the case for open bite patients. For example, consider open bites in growing subjects. In mild to moderate open bites, orthodontists would routinely attempt nonsurgical treatment, as they may be optimistic that habit and growth modification would allow correction of open bites that are not severe. Orthodontic treatment may also be recommended to correct severe open bites in adolescents to either eliminate orthognathic surgery or to reduce the severity of the vertical discrepancy. Thus, we might routinely observe orthodontists trying nonsurgical treatment for the majority of their adolescent patients, regardless of the severity of the problem.

On the other hand, orthodontists may take the opposite approach with adults, recommending surgery as the primary method of correction for moderate to severe open bites, citing a lack of growth as a reason to consider more aggressive techniques. Some orthodontists might even recommend that adults with mild open bites undergo surgery to maximize the chance for long-term stability. They may reason that adults have demonstrated a persistence of their vertical relationships and that more aggressive treatment will be needed to change and retain these new vertical relationships. The evidence for long-term stability of surgical versus nonsurgical therapy is covered in the next section of this chapter.

A deduction from this discussion, though, is that it becomes potentially difficult to compare success rates in adolescent and adult open bite patients due to the differing approaches that may be employed. Perhaps the areas of greatest overlap might be recommendations for adolescents with severe open bites, for which orthodontists might recommend surgical or nonsurgical treatment, and adults with mild open bites, which might be amenable to both surgical or nonsurgical treatment options (Figure 7.4). Ultimately, evidence about treatment and stability should allow us to decide how to best recommend treatment. Additionally, evidence to guide us on managing cases that relapse would be helpful for future patients.

Retention

For the typical orthodontic patient, alignment is the major factor to consider during the retention phase. However, for open bite patients, orthodontists must grapple with the difficult task of maintaining the vertical correction that was accomplished during treatment. Many different strategies have been proposed, including positioners, spurs or holes in retainers, elastics, posterior bite blocks, and Essix style retainers. A challenge with all of these strategies is the willingness of patients to adhere to the use of these various types

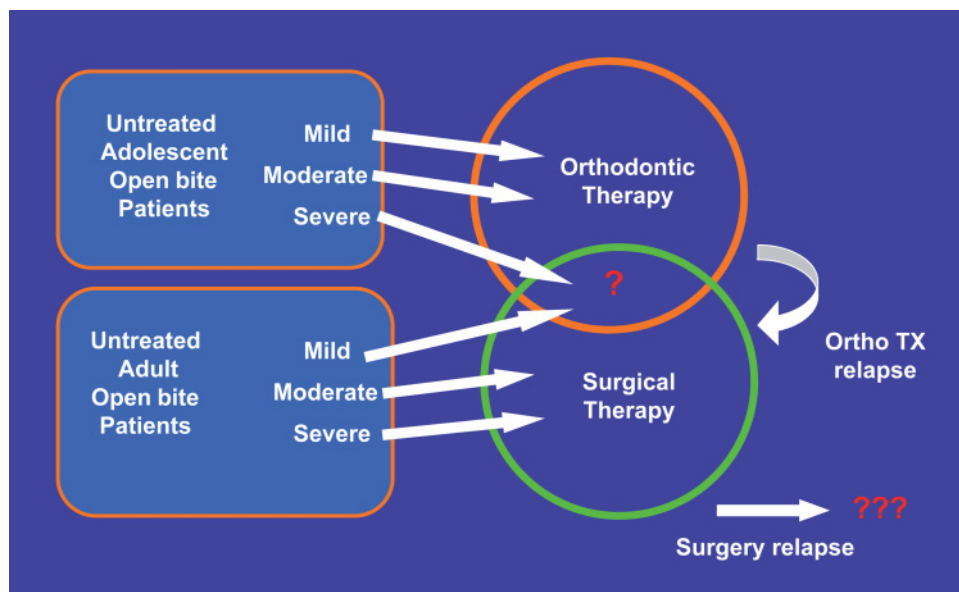


Figure 7.4 Strategies for adolescents and adults.

of retention devices. There is little evidence to support any of these various retention strategies, and thus, orthodontists are essentially on their own when it comes to retention of corrected open bites. In the authors' opinion, Essix style retainers may offer a good option because they are usually well-accepted by patients and the occlusal coverage causes patients to contact mainly on the posterior teeth, preventing overeruption of those teeth. This posterior eruption and increase in posterior facial height has been reported as a cause of relapse in surgical studies (Denison, Kokich & Shapiro 1989; Fischer, von Konow & Brattstrom 2000). Of course, for patients who do have tongue posture problems, retainers with spurs or holes in the palate can help to address the etiologic factor. The effectiveness of these types of retention devices will depend on the patient's compliance.

Evidence on Long-Term Stability of Open Bite Correction

The evidence on long-term stability of open bite treatment is relatively sparse and consists primarily of collections of case series. In a few studies, different types of nonsurgical interventions have been compared, such as extraction versus nonextraction. Additionally, some studies have compared various types of surgical correction, such as one versus two-jaw surgery or one versus multiple segment LeFort. In assessing the state of the evidence for long-term stability, it is most efficient to seek out the highest levels of evidence. Two systematic reviews have addressed the issue of long-term stability of open bite treatment. The first review was published in 2002 (Huang 2002), and the second is scheduled for publication in 2011 (Greenlee et al. 2011). These two reviews will be described and com-

pared because they provide an opportunity to follow the development of systematic review methods over the past decade.

The first systematic review (Huang 2002) listed three aims: (1) to identify and review articles that addressed the stability of open bite therapy, (2) to compare long-term stability of nonsurgical and surgical treatment, and (3) to critically assess the evidence and suggest directions for future research. This review searched only one database, PubMed, as well as reference lists of retrieved articles. Selection of studies for inclusion, as well as data abstraction, was performed by one author. The inclusion criteria used were relatively simple—the studies had to have samples of at least five subjects, and they had to address long-term stability of open bite treatment. Surprisingly, only six nonsurgical studies (Huang et al. 1990; Nemeth & Isaacson 1974; Frankel & Frankel 1983; Lopez-Gavito et al. 1985; Katsaros & Berg 1993; Kim et al. 2000) and 15 surgical studies (Ermel et al. 1999; Denison, Kokich & Shapiro 1989; Fischer, von Konow & Brattstrom 2000; Turvey, Journot & Epker 1976; Reitzik et al. 1990; Haymond et al. 1991; McCance, Moss & James 1992; Oliveira & Bloomquist 1997; Hoppenreijis et al. 1997; Hoppenreijis et al. 1998a; Lo & Shapiro 1998; Arpornmaeklong & Heggie 2000; Proffit et al. 2000; Moldez et al. 2000; Swinnen K et al. 2001) qualified for final inclusion.

The six nonsurgical studies reported on various orthodontic therapies, including conventional orthodontic appliances, cribs, functional appliances, headgear, extractions, and the multiloop edgewise technique (MEAW). Most studies reported on adolescent patients. The sample sizes ranged from 13 to 41 subjects, and the follow-up times were from 1 to 18 years after completion of orthodontic treatment. The review reported values at two time points: the percent with positive overbite at the end of treatment (treatment success) and the percent of subjects who had positive overbite at the long-term follow-up (stability). The product of the two values was the overall success. For example, if a study reported 93% treatment success, and of the successful cases, 100% long-term stability, the overall success was $0.93 \times 1.0 = 93\%$. Four of the 6 nonsurgical studies reported data from which these values could be calculated, and the long-term success of these studies ranged from 75% to 93% (Table 7.4). Shortcomings of many of the nonsurgical studies were the potential for selection bias, small sample sizes, loss to follow-up, and lack of comparison subjects.

Thirteen of the fifteen surgical studies reported on maxillary surgery, some with concomitant mandibular surgery. These patients were primarily adults. Most of these studies investigated LeFort osteotomies with posterior impaction. Only two studies reported solely on mandibular procedures, the reverse-L osteotomy and the bilateral sagittal split osteotomy. The surgical studies ranged in size from 9 to 267 subjects, and the follow-up times

Table 7.4 Treatment success, stability, and long-term success—nonsurgical studies.

Study	Follow-up (years)	TX Success (%)	Stability (%)	Overall Success (%)
Lopez-Gavito et al. (1985)	11–6	93	100	93
Huang et al. (1990)	5–3	88	100	88
Katsaros & Berg (1993)	≥1	75	100	75
Kim et al. (2000)	2–8	100	93	93

Table 7.5 Treatment success, stability, and long-term success—surgical studies.

Study	Follow-up (years)	TX Success (%)	Stability (%)	Overall Success (%)
Denison, Kokich & Shapiro (1989)	3–0*	100	79	79
Reitzik et al. (1990)	≥1 (post-op)	100	100	100
Haymond et al. (1991)	≥1 (post-op)	100	84	84
Ermel et al. (1999)	7–3	100	88	88
Hoppenreijns et al. (1997)	5–9	100	81	81
Lo & Shapiro (1998)	5–10	100	75	75
Proffit et al. (2000)	5–4	100	88	88
Moldez et al. (2000)	≥5	100	91	91
Fischer, von Konow & Brattstrom (2000)	≥2 (post-op)	100	71	71
Swinnen et al. (2001)	1 (post-op)	100	89	89

*Value is post-orthodontic treatment unless otherwise noted. Post-op, postoperative (indicating time after surgery).

were from 1 to many years after surgery. Ten of the surgical studies reported data that could be used to calculate long-term stability. Success at the end of treatment was not typically reported. Since surgical procedures were performed for these subjects, it was assumed that a positive overbite was attained for all subjects at the end of treatment. Using the assumption of 100% treatment success, overall success then depended only on long-term stability, which was reported to be between 71% and 100% (Table 7.5). Limitations of the surgical studies were similar to those for nonsurgical studies, with several additional issues. For example, surgical studies often used relatively short follow-up times, with many studies reporting long-term data at 1 year after surgery, rather than 1 year after orthodontics. The 1-year postsurgical time could have coincided with debanding, at which time stability was still untested. Also, the surgical studies tended to have limited data on dental and skeletal relationships, especially from the pretreatment time period. In fact, many studies reported initial data from the presurgical time period, when presurgical orthodontics had already been performed. This could have impacted dental and skeletal parameters, most notably, the vertical incisor relationships.

In summarizing the first review on long-term stability, we can return to the three questions that it posed. (1) Six nonsurgical and 15 surgical studies met the relatively liberal inclusion criteria. These studies were described in the review, and most were reports using case series, a design that is low in the hierarchy of evidence. Naturally, these studies are susceptible to bias from selection. In general, the nonsurgical studies reported on adolescents, and the surgical studies reported on adults. Pretreatment overbite values and mandibular plane angles appeared to be similar for the surgical and nonsurgical studies. (2) The reports for long-term success, as measured by positive incisor overlap at the follow-up time, were 75% to 93% for nonsurgical studies and from 71% to 100% for surgical studies. These success rates were relatively similar for surgical and nonsurgical studies, despite the obvious differences in treatment approach, as well as the difference in age/growth

status. (3) The studies were generally of low quality, and several recommendations were made for future research, such as the standardization of data gathered and the time points that should be included. Additionally, consecutive or random sampling was recommended to guard against selection bias. Finally, studies should report on end-of-treatment success and long-term stability, allowing the determination of the long-term success of treatment. No studies could be located that reported on long-term stability for therapies such as glos-sotomy, myofunctional therapy, tonsillectomy/adenoidectomy, magnets, or posterior biteplates.

The second, more recent systematic review on open bite stability (Greenlee et al. 2011) was published in 2011. The objective was to review and compile evidence for stability of surgical and nonsurgical therapies for anterior open bite malocclusion. This review searched three databases, reference lists, and the gray literature. All study selection, data abstraction, and quality assessment was done in duplicate.

Inclusion criteria for in the final selection were as follows:

- Human studies
- Stability outcome assessed at posttreatment follow-up ≥ 1 year
- Negative overbite/presence of open bite pretreatment or presurgery, as defined by vertical measures
- Corrective therapy for open bite malocclusion adequately described

Exclusion criteria were as follows:

- Case reports with $\leq$ five subjects
- Editorials, opinion, or philosophy articles with no new data
- Subjects with other craniofacial pathology or anomalies potentially influencing stability or complicating treatment (syndromes, periodontal disease, cleft lip/palate, trauma)
- Mixed measures of open bite (combining horizontal and vertical measures)

The data were analyzed by pooling the results from the studies, using a random effects model for continuous data. Additionally, data from studies which reported the success and long-term stability were analyzed in a fashion similar to the prior review (percent stable long term). Most articles had shortcomings in the reporting of subject selection methods and dropouts, the analysis of confounders, and the lack of controls or comparison groups.

This review identified 16 studies that qualified for inclusion, 7 nonsurgical studies and 9 surgical. The initial and posttreatment values for overbite were similar between the surgical and nonsurgical groups (-3 mm initial, $+1.5$ posttreatment). At the long-term follow-up, though, the surgical group appeared to exhibit slightly greater stability (Figures 7.5 and 7.6). These were all uncontrolled studies of very different techniques and study populations, so caution must be exercised in any direct comparisons of these two treatment modalities.

The secondary analysis of the percentage of long-term success indicated an average surgical stability of 82% and an average nonsurgical stability of 75%. Again, the results appear to favor the surgical treatment slightly, but direct comparison should be avoided. This review did include a study comparing extraction versus nonextraction therapy with

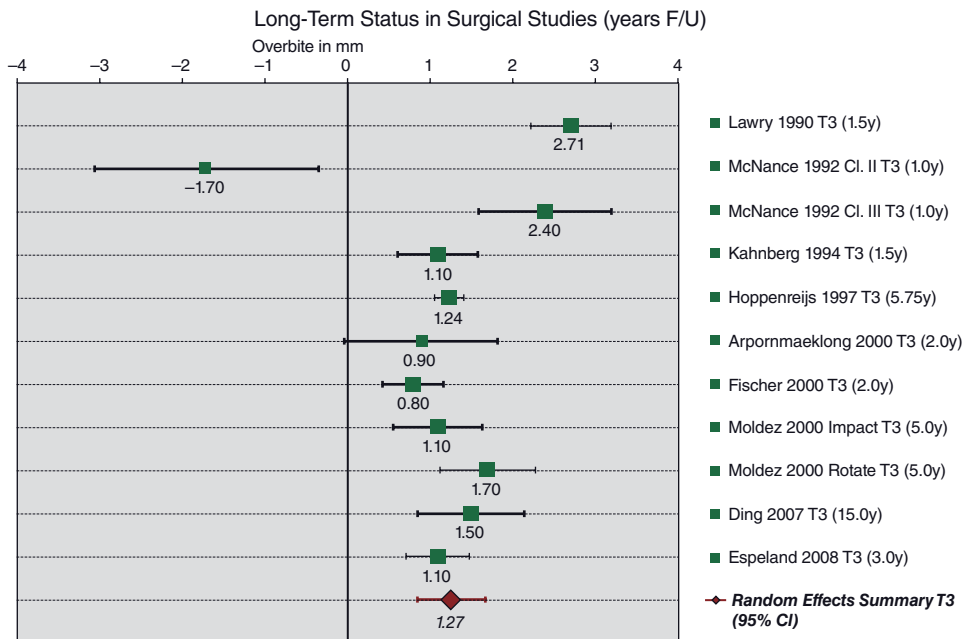


Figure 7.5 Long-term follow-up of surgical studies.

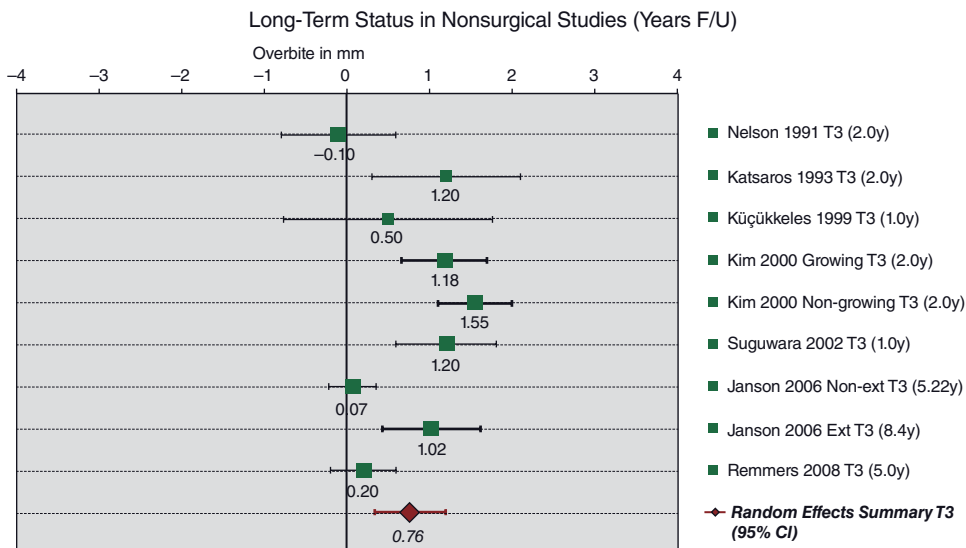


Figure 7.6 Long-term follow-up of nonsurgical studies.



Figure 7.7 Pretreatment (A), posttreatment (B), and 2 years posttreatment (C).

conventional orthodontics, which found that extractions were associated with better long-term stability (Janson et al. 2006). This may be attributed to the benefits of bite deepening that typically accompany space closure. (An example of relatively good long-term stability for an adult open bite patient treated with four first premolar extractions is shown in Figure 7.7).

Conclusions from the Two Systematic Reviews

As stated earlier, these two reviews allow an opportunity to observe the development of systematic review methods. The first review is an example of an earlier systematic review, which incorporates many elements that are common to systematic reviews but used less rigorous methods than the contemporary standards, as the guidelines have evolved over the past several decades. The latter review follows many of the guidelines that have been recommended in the *Cochrane Handbook of Systematic Reviews of Interventions* (Swinnen K et al. 2001). This handbook has assisted many authors in employing consistent, reproducible, and rigorous methods for the conduct of their reviews, and the Cochrane group provides software that can be used in all aspects of performing a systematic review. The Cochrane Collaboration should be commended for their efforts in encouraging and facilitating the highest quality reviews for all areas of health care.

Although the inclusion criteria for the two reviews differ slightly, as do the included articles, both reviews seem to arrive at similar conclusions—the evidence identified by the reviews is of limited quality, the ages of patients in the surgical and nonsurgical groups are very different, their pretreatment severity (measured by overbite and mandibular plane angle) appear to be quite similar, the potential for selection bias is high, and standardized follow-up times and data collection are critical for comparison with other data. Importantly, the long-term rates for stable correction appear to be in the 70%–80% range, with the suggestion that surgical stability rates may be slightly better. Perhaps one of the most critical populations to investigate is adults with mild to moderate open bite, as surgery may often be recommended for these patients. We should have good evidence that this treatment modality offers better treatment outcomes and better stability, as it has higher risks and costs.

Gaps in Knowledge

Having discussed the evidence that is available on long-term stability of anterior open bite, several gaps in our knowledge are evident. For example, are anterior open bites harmful to the dentition or masticatory system in the short or long term? How do we determine the most appropriate therapy for adolescents with severe open bites or adults with mild to moderate open bites? Are a large percentage of adults who seek surgical care seeking retreatment after relapse of conventional orthodontic treatment during their adolescent years? In the case of surgical cases that relapse, should surgery be considered again, or should other options be considered? Finally, what are the most effective retention methods for open bite patients?

Future Directions for Open Bite Treatment

Several new therapies for addressing open bites have emerged in the past decade. Although maxillary surgery is often considered the more stable approach for open bite correction (Swinnen K et al. 2001; Epker & Fish 1977), mandibular surgeries, including the inverted-L and the sagittal split osteotomy, have been reported occasionally (Reitzik et al. 1990; Oliveira & Bloomquist 1997). Recently, some have been advocating the sagittal split osteotomy with rigid fixation as a stable and predictable option that offers some advantages to maxillary surgery. One advantage is for patients with mandibular retrognathia; a mandibular surgery allows correction of vertical and anteroposterior discrepancies with surgery in one jaw. Another reason is that LeFort I surgery can be associated with undesirable soft tissue changes in the midface, and mandibular surgery prevents these negative sequelae. A patient who was treated with counterclockwise rotation of the mandible is presented in Figure 7.8. The primary argument against mandibular surgery for correction of open bite is that maxillary surgery provides better long-term stability (Proffit et al. 2000; Hoppenreijds et al. 2001). However, there is some recent evidence that rigid fixation may assist with long-term stability when open bites are corrected with bilateral sagittal split osteotomy (Bisase, Johnson & Stacey 2009).

Another contemporary approach to correcting open bites in the permanent dentition is with temporary anchorage devices. Proponents suggest using miniscrews or miniplates in the maxilla to provide the anchorage necessary to intrude the posterior teeth, thus allowing

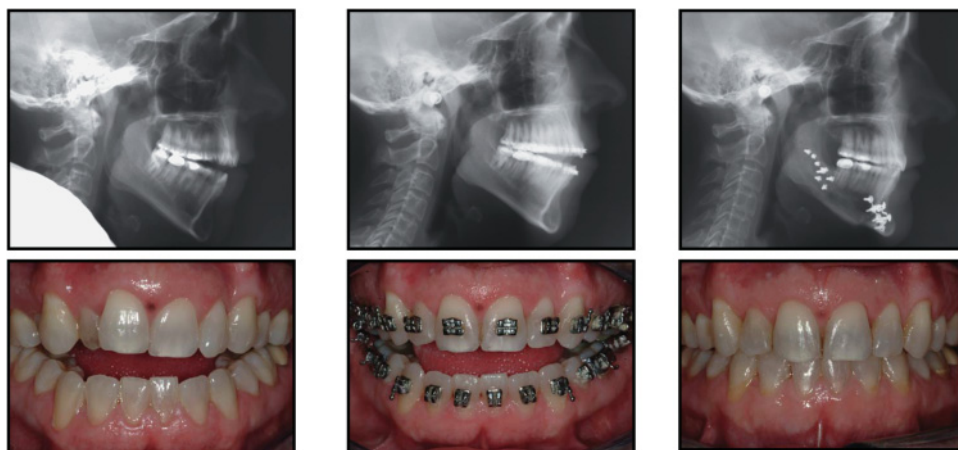


Figure 7.8 Pretreatment, presurgery, and posttreatment cephs and photos of an adult open bite patient treated with mandibular counterclockwise rotation and advancement genioplasty.

autorotation and closure of the open bite. In a sense, this is similar to the surgical Schuchart technique, only instead of being performed by a surgeon in a couple of hours it is performed by the orthodontist over a period of several months. Several reports confirm that it is possible to correct open bites with temporary anchorage devices (TADs), but long-term data on stability is not available at this time (Seres & Kocsis 2009; Sakai et al. 2008; Sherwood 2007; Kuroda et al. 2007; Kravitz & Kusnoto 2007; Xun, Zeng & Wang 2007; Kuroda, Katayama & Takano-Yamamoto 2004; Erverdi, Keles & Nanda 2004; Umemori et al. 1999; Akay et al. 2009; Janson et al. 2008).

Occlusal equilibration has also been proposed as a method to address open bites in patients who have relapse after orthodontic treatment (Janson et al. 2008). While this method can provide a relatively quick solution for minor relapse, the study provides follow-up for a only few months after the equilibration, and longer-term data are needed.

Finally, a combination of corticotomy and TADs has been suggested as a means to correct anterior open bite. One case report describes the success of this technique in which corticotomy allows block intrusion of posterior teeth (pulling against anchorage provided by miniplates), with subsequent autorotation and closure of the open bite (Akay et al. 2009).

As with all new techniques, evidence is needed to understand the mechanism of correction and the subsequent rates of long-term stability. Of course, one must always weigh risks, benefits, costs, long-term success, and patient preferences in deciding on the most appropriate therapy for an individual patient.

Summary

This chapter has attempted to describe various aspects of open bite malocclusion, including prevalence, etiology, treatment, and long-term stability. It has also explored some new therapies that have recently been proposed. The goal of this chapter is to assist the prac-

itioner in understanding the current state of the evidence, especially in the area of long-term stability, as a means to improve our ability to counsel our open bite patients. Undoubtedly, we will continue to develop and improve upon methods and techniques to treat open bite patients. In addition, research directed at understanding the etiology of open bite malocclusions would allow us to recommend the most appropriate strategies for treatment and retention. Perhaps as techniques for real-time, 3-D imaging improve, we may have the ability to better understand the contribution of the tongue, airway, and other oral structures to an individual's malocclusion. This would allow orthodontists to identify and address the underlying etiologic agents. In the meantime, orthodontists should continue to provide patients with the current, best evidence regarding open bite correction and stability and allow patients to be active participants in making informed treatment decisions.

References

- Adair, S.M., Milano, M., Lorenzo, I. et al., 1995. Effects of current and former pacifier use on the dentition of 24- to 59-month-old children. *Pediatric Dentistry* 17, pp. 437–444.
- Akay, M.C., Aras, A., Gunbay, T. et al., 2009. Enhanced effect of combined treatment with corticotomy and skeletal anchorage in open bite correction. *Journal of Oral Maxillofacial Surgery* 67, pp. 563–569.
- Arpornmaeklong, P. & Heggie, A.A. 2000. Anterior open-bite malocclusion: stability of maxillary repositioning using rigid internal fixation. *Australian Orthodontics Journal* 16, pp. 69–81.
- Asdaghi Mamaghani, S.M., Bode, H. & Ehmer, U., 2008. Paralysis in adults of two different age groups—a cross-sectional study. *Journal of Orofacial Orthopedics* 69, pp. 240–256.
- Bakke, M. & Michler, L., 1991. Temporalis and masseter muscle activity in patients with anterior open bite and craniomandibular disorders. *Scandinavian Journal of Dental Research* 99, pp. 219–228.
- Ball, J.V. & Horrocks, E.N., 1995. Partial glossectomy for the treatment of anterior open bite. A case report. *British Journal of Orthodontics* 22, pp. 185–189.
- Benkert, K.K., 1997. The effectiveness of orofacial myofunctional therapy in improving dental occlusion. *International Journal Orofacial Myology* 23, pp. 35–46.
- Bisase, B., Johnson, P. & Stacey, M., 2009. Closure of the anterior open bite using mandibular sagittal split osteotomy. *The British Journal of Oral & Maxillofacial Surgery*. 48:352–355. Epub Sep 16.
- Bjork, A., 1969. Prediction of mandibular growth rotation. *American Journal of Orthodontics* 55, pp. 585–599.
- Bresolin, D., Shapiro, P.A., Shapiro, G.G. et al., 1983. Mouth breathing in allergic children: its relationship to dentofacial development. *American Journal of Orthodontics* 83, pp. 334–340.
- Brunelle, J.A., Bhat, M. & Lipton, J.A., 1996. Prevalence and distribution of selected occlusal characteristics in the US population, 1988–1991. *Journal of Dental Research* 75, pp. 706–713.
- Cangialosi, T.J., 1984. Skeletal morphologic features of anterior open bite. *American Journal of Orthodontics* 85, pp. 28–36.
- Carmagnani, F.G., Goncalves, G.K., Correa, M.S. et al., 2007. Occlusal characteristics in cerebral palsy patients. *Journal Dentistry for Children* 74, pp. 41–45.
- Ding, Y., Xu, T.M., Lohrmann, B. et al., 2007. Stability following combined orthodontic-surgical treatment for skeletal anterior open bite—a cephalometric 15-year follow-up study. *Journal of Orofacial Orthopedics* 68, pp. 245–256.
- Denison, T.F., Kokich, V.G. & Shapiro, P.A., 1989. Stability of maxillary surgery in openbite versus nonopenbite malocclusions. *The Angle Orthodontist* 59, pp. 5–10.

- Epker, B.N. & Fish, L., 1977. Surgical-orthodontic correction of open-bite deformity. *American Journal of Orthodontics* 71, pp. 278–299.
- Ermel, T., Hoffmann, J., Alfter, G. et al., 1999. Long-term stability of treatment results after upper jaw segmented osteotomy according to Schuchardt for correction of anterior open bite. *Journal of Orofacial Orthopedics* 60, pp. 236–245.
- Erturk, N. & Dogan, S., 1991. The effect of neuromuscular diseases on the development of dental and occlusal characteristics. *Quintessence International* 22, pp. 317–321.
- Erverdi, N., Keles, A. & Nanda, R., 2004. The use of skeletal anchorage in open bite treatment: a cephalometric evaluation. *The Angle Orthodontist* 74, pp. 381–390.
- Espeland L., Dowling P.A., Mobarak K.A., et al., 2008. Three-year stability of open-bite correction by 1-piece maxillary osteotomy. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 60–66.
- Fields, H.W., Warren, D.W., Black, K. et al., 1991. Relationship between vertical dentofacial morphology and respiration in adolescents. *American Journal of Orthodontics and Dentofacial Orthopedics* 99, pp. 147–154.
- Fischer, K., von Konow, L. & Brattstrom, V., 2000. Open bite: stability after bimaxillary surgery—2-year treatment outcomes in 58 patients. *European Journal Orthodontics* 22, pp. 711–718.
- Frankel, R. & Frankel, C., 1983. A functional approach to treatment of skeletal open bite. *American Journal of Orthodontics* 84, pp. 54–68.
- Garliner, D. & Gables, C., 1982. Treatment of the open bite, utilizing myofunctional therapy. *Fortschritte der Kieferorthopädie* 43, pp. 295–307.
- Ghafari, J., Clark, R.E., Shofer, F.S. et al., 1988. Dental and occlusal characteristics of children with neuromuscular disease. *American Journal of Orthodontics and Dentofacial Orthopedics* 93, pp. 126–132.
- Gois, E.G., Ribeiro-Junior, H.C., Vale, M.P. et al., 2008. Influence of nonnutritive sucking habits, breathing pattern and adenoid size on the development of malocclusion. *The Angle Orthodontist* 78, pp. 647–654.
- Greenlee, G., Huang, G., Chen, S. et al., 2011. Stability of anterior openbite malocclusion: a meta-analysis. *American Journal of Orthodontics and Dentofacial Orthopedics* 139(2), pp. 154–169.
- Haruki, T., Kishi, K. & Zimmerman, J., 1999. The importance of orofacial myofunctional therapy in pediatric dentistry: reports of two cases. *ASDC Journal of Dentistry Children* 66, pp. 103–109.
- Haymond, C.S., Stoelinga, P.J., Blijdorp, P.A. et al., 1991. Surgical orthodontic treatment of anterior skeletal open bite using small plate internal fixation. One to five year follow-up. *International Journal Orofacial Myology* 20, pp. 223–227.
- Higgins, J.P.T. & Green, S., eds., 2006. Cochrane handbook for systematic reviews of interventions 4.2.6 (updated September, 2006). In: *The Cochrane Library*, Issue 4. Chichester, UK: John Wiley & Sons.
- Hoppenreijts, T.J., Freihofer, H.P., Stoelinga, P.J. et al., 1997. Skeletal and dento-alveolar stability of Le Fort I intrusion osteotomies and bimaxillary osteotomies in anterior open bite deformities. A retrospective three-centre study. *International Journal of Oral Maxillofacial Surgery* 26, pp. 161–175.
- Hoppenreijts, T.J., van der Linden, F.P., Freihofer, H.P. et al., 1998a. Stability of transverse maxillary dental arch dimensions following orthodontic-surgical correction of anterior open bites. *International Journal of Adult Orthodontics and Orthognathic Surgery* 13, pp. 7–22.
- Hoppenreijts, T.J., Freihofer, H.P., Stoelinga, P.J. et al., 1998b. Condylar remodelling and resorption after Le Fort I and bimaxillary osteotomies in patients with anterior open bite. A clinical and radiological study. *International Journal of Oral Maxillofacial Surgery* 27, pp. 81–91.
- Hoppenreijts, T.J., Freihofer, H.P., Stoelinga, P.J. et al., 2001. Stability of orthodontic-maxillofacial surgical treatment of anterior open bite deformities. *Nederlands tijdschrift voor tandheelkunde* 108, pp. 173–178.

- Hotokezaka, H., Matsuo, T., Nakagawa, M. et al., 2001. Severe dental open bite malocclusion with tongue reduction after orthodontic treatment. *The Angle Orthodontist* 71, pp. 228–236.
- Huang, G.J., Justus, R., Kennedy, D.B. et al., 1990. Stability of anterior openbite treated with crib therapy. *The Angle Orthodontist* 60, pp. 17–24; discussion pp. 25–26.
- Huang, G. 2002. Long-term stability of anterior open-bite therapy: a review. *Seminars in Orthodontics* 8, pp. 162–172.
- Janson, G., Valarelli, F.P., Beltrao, R.T. et al., 2006. Stability of anterior open-bite extraction and nonextraction treatment in the permanent dentition. *American Journal of Orthodontics and Dentofacial Orthopedics* 129, pp. 768–774.
- Janson, G., Crepaldi, M.V., de Freitas, K.M. et al., 2008. Evaluation of anterior open-bite treatment with occlusal adjustment. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 10–11.
- Jolley, C., Huang, G., Greenlee, G. et al., 2010. The dental effects of interceptive treatment in a Medicaid population: results from a randomized clinical trial. *American Journal of Orthodontics and Dentofacial Orthopedics* 137(3), pp. 324–333.
- Justus, R., 1976. Treatment of anterior open bite; a cephalometric and clinical study. *ADM* 33, pp. 17–40.
- Kahnberg, K.E., Zouloumis, L. & Widmark, G., 1994. Correction of open bite by maxillary osteotomy. A comparison between bone plate and wire fixation. *Journal of Craniomaxillofacial Surgery* 22, 250–255.
- Katsaros, C. & Berg, R., 1993. Anterior open bite malocclusion: a follow-up study of orthodontic treatment effects. *European Journal Orthodontics* 15, pp. 273–280.
- Kawakami, S., Yokozeke, M., Takahashi, T. et al., 2005. Siblings with spaced arches treated with and without partial glossectomy. *American Journal of Orthodontics and Dentofacial Orthopedics* 127, pp. 364–373.
- Kiliaridis, S., Mejersjo, C. & Thilander, B., 1989. Muscle function and craniofacial morphology: a clinical study in patients with myotonic dystrophy. *European Journal Orthodontics* 11, pp. 131–138.
- Kim, Y.H., Han, U.K., Lim, D.D. et al., 2000. Stability of anterior openbite correction with multiloop edgewise archwire therapy: a cephalometric follow-up study. *American Journal of Orthodontics and Dentofacial Orthopedics* 118, pp. 43–54.
- Kelly, J., Sanchez, M. & Kirk, L.V., 1973. *An assessment of the occlusion of teeth of children*. Washington, DC: National Center for Health Statistics.
- Kelly, J. & Harvey, C., 1977. *An assessment of the teeth of youths 12–17 years*. Washington, DC: National Center for Health Statistics.
- Kravitz, N.D. & Kusnoto, B., 2007. Posterior impaction with orthodontic miniscrews for openbite closure and improvement of facial profile. *World Journal of Orthodontics* 8, pp. 157–166.
- Kucukkeles, N., Acar, A., Demirkaya, A.A. et al. 1999. Cephalometric evaluation of open bite treatment with NiTi arch wires and anterior elastics. *American Journal of Orthodontics and Dentofacial Orthopedics* 116, pp. 555–562.
- Kuroda, S., Katayama, A. & Takano-Yamamoto, T., 2004. Severe anterior open-bite case treated using titanium screw anchorage. *The Angle Orthodontist* 74, pp. 558–567.
- Kuroda, S., Sakai, Y., Tamamura, N. et al., 2007. Treatment of severe anterior open bite with skeletal anchorage in adults: comparison with orthognathic surgery outcomes. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 599–605.
- Lawry, D.M., Heggie, A.A., Crawford, E.C. et al., 1990. A review of the management of anterior open bite malocclusion. *Australian Orthodontic Journal* 11, pp. 147–160.
- Linder-Aronson, S. 1970. Adenoids—their effect on the mode of breathing and nasal air flow and their relationship to characteristics of the facial skeleton and dentition. *Acta Oto-laryngologica* (Suppl), p. 265.

- Lo, F.M. & Shapiro, P.A., 1998. Effect of presurgical incisor extrusion on stability of anterior open bite malocclusion treated with orthognathic surgery. *International Journal of Adult Orthodontics and Orthognathic Surgery* 13, pp. 23–34.
- Lopez-Gavito, G., Wallen, T.R., Little, R.M. et al., 1985. Anterior open-bite malocclusion: a longitudinal 10-year postretention evaluation of orthodontically treated patients. *American Journal of Orthodontics* 87, pp. 175–186.
- Mahony, D., Karsten, A. & Linder-Aronson, S., 2004. Effects of adenoidectomy and changed mode of breathing on incisor and molar dentoalveolar heights and anterior face heights. *Australian Orthodontic Journal* 20, pp. 93–98.
- Mason, R.M., 2008. A retrospective and prospective view of orofacial myology. *International Journal Orofacial Myology* 34, pp. 5–14.
- McCance, A.M., Moss, J.P. & James, D.R., 1992. Stability of surgical correction of patients with Skeletal III and Skeletal II anterior open bite, with increased maxillary mandibular planes angle. *European Journal Orthodontics* 14, pp. 198–206.
- Moldez, M.A., Sugawara, J., Umemori, M. et al., 2000. Long-term dentofacial stability after bimaxillary surgery in skeletal Class III open bite patients. *International Journal of Adult Orthodontics Orthognathic Surgery* 15, pp. 309–319.
- Morel-Verdebout, C., Botteron, S. & Kiliaridis, S., 2007. Dentofacial characteristics of growing patients with Duchenne muscular dystrophy: a morphological study. *European Journal Orthodontics* 29, pp. 500–507.
- Nelson, A.H. & Nelson, D.L., 1991. A collaborative research study to investigate the relationship between size of interlabial gap and long term dental status in an anterior open bite population. *International Journal of Orofacial Myology* 17, pp. 3–6.
- Nemeth, R.B. & Isaacson, R.J., 1974. Vertical anterior relapse. *American Journal of Orthodontics* 65, pp. 565–585.
- Oliveira, J.A. & Bloomquist, D.S., 1997. The stability of the use of bilateral sagittal split osteotomy in the closure of anterior open bite. *International Journal of Adult Orthodontics Orthognathic Surgery* 12, pp. 101–108.
- Pedrin, F., Almeida, M.R., Almeida, R.R. et al., 2006. A prospective study of the treatment effects of a removable appliance with palatal crib combined with high-pull chin cup therapy in anterior open-bite patients. *American Journal of Orthodontics and Dentofacial Orthopedics* 129, pp. 418–423.
- Popovich, F. & Thompson, G.W., 1973. Thumb- and finger-sucking: its relation to malocclusion. *American Journal of Orthodontics* 63, pp. 148–155.
- Proffit, W.R., 1978. Equilibrium theory revisited: factors influencing position of the teeth. *The Angle Orthodontist* 48, pp. 175–86.
- Proffit, W.R., Bailey, L.J., Phillips, C. et al., 2000. Long-term stability of surgical open-bite correction by Le Fort I osteotomy. *The Angle Orthodontist* 70, pp. 112–117.
- Reitzik, M., Barer, P.G., Wainwright, W.M. et al., 1990. The surgical treatment of skeletal anterior open-bite deformities with rigid internal fixation in the mandible. *American Journal of Orthodontics and Dentofacial Orthopedics* 97, pp. 52–57.
- Remmers, D., Van't Hullenaar, R.W., Bronkhorst, E.M. et al. 2008. Treatment results and long-term stability of anterior open bite malocclusion. *Orthodontics & craniofacial research* 11, pp. 32–42.
- Rogers, A.P., 1927. Openbite cases involving tongue habits. *International Journal of Orthodontics* 13, pp. 837–844.
- Ruff, R.M., 1985. Orthodontic treatment and tongue surgery in a class III open-bite malocclusion. A case report. *The Angle Orthodontist* 55, pp. 155–166.
- Sakai, Y., Kuroda, S., Murshid, S.A. et al., 2008. Skeletal Class III severe openbite treatment using implant anchorage. *The Angle Orthodontist* 78, pp. 157–166.
- Sassouni, V., 1969. A classification of skeletal facial types. *American Journal of Orthodontics* 55, pp. 106–123.

- Sassouni, V., Friday, G.A., Shnorhokian, H., et al. 1985. The influence of perennial allergic rhinitis on facial type and a pilot study of the effect of allergy management on facial growth patterns. *Annals of Allergy* 54, pp. 493–497.
- Schudy, F.F., 1965. The roation of the mandible reulsting from growth: its implications in orthodontic treatment. *The Angle Orthodontist* 55, pp. 36–50.
- Seres, L. & Kocsis, A., 2009. Closure of severe skeletal anterior open bite with zygomatic anchorage. *Journal of Craniofacial Surgery* 20, pp. 478–482.
- Sherwood, K., 2007. Correction of skeletal open bite with implant anchored molar/bicuspid intrusion. *Oral and Maxillofacial Surgery Clinics of North America* 19, pp. 339–350.
- Souki, B.Q., Pimenta, G.B., Souki, M.Q. et al., 2009. Prevalence of malocclusion among mouth breathing children: do expectations meet reality? *International Journal of Pediatric Otorhinolaryngology* 73, pp. 767–773.
- Straub, W.J., 1960. Malfunction of the tongue. *American Journal of Orthodontics* 46, pp. 404–424.
- Straub, W.J., 1961. Malfunction of the tongue, part II. *American Journal of Orthodontics* 47, pp. 598–617.
- Straub, W.J., 1962. Malfunction of the tongue, part III. *American Journal of Orthodontics* 48, pp. 486–503.
- Subtelny, J.D. & Sakuda, M., 1964. Openbite: diagnosis and treatment. *American Journal of Orthodontics* 50, pp. 37–58.
- Sugawara 2000 should be 2002 – Sugawara, J., Baik, U.B., Umemori, M. et al., 2002. Treatment and posttreatment dentoalveolar changes following intrusion of mandibular molars with application of a skeletal anchorage system (SAS) for open bite correction. *International journal of Adult Orthodontics and Orthognathic Surgery* 1, 243–253.
- Swineheart, E.W., 1942. A clinical study of openbite. *American Journal of Orthodontics and Oral Surgery* 28, pp. 18–34.
- Swinnen, K., Politis, C., Willems, G. et al., 2001. Skeletal and dento-alveolar stability after surgical-orthodontic treatment of anterior open bite: a retrospective study. *European Journal Orthodontics* 23, pp. 547–557.
- Turvey, T.A., Journot, V. & Epker, B.N., 1976. Correction of anterior open bite deformity: a study of tongue function, speech changes, and stability. *Journal Maxillofacial Surgery* 4, pp. 93–101.
- Umemori, M., Sugawara, J., Mitani, H. et al., 1999. Skeletal anchorage system for open-bite correction. *American Journal of Orthodontics and Dentofacial Orthopedics* 115, pp. 166–174.
- Verrastro, A.P., Stefani, F.M., Rodrigues, C.R. et al., 2007. Occlusal and orofacial myofunctional evaluation in children with anterior open bite before and after removal of pacifier sucking habit. *International Journal of Orthodontics* 18, pp. 19–25.
- Vig, K.W., 1998. Nasal obstruction and facial growth: the strength of evidence for clinical assumptions. *American Journal of Orthodontics and Dentofacial Orthopedics* 113, pp. 603–611.
- Vittek, J., Winik, S., Winik, A. et al., 1994. Analysis of orthodontic anomalies in mentally retarded developmentally disabled (MRDD) persons. *Special Care in Dentistry* 14, pp. 198–202.
- Warren, J.J., Slayton, R.L., Bishara, S.E. et al., 2005. Effects of nonnutritive sucking habits on occlusal characteristics in the mixed dentition. *Pediatric Dentistry* 27, pp. 445–450.
- Worms, F.W., Meskin, L.H. & Isaacson, R.J., 1971. Open-bite. *American Journal of Orthodontics* 59, pp. 589–595.
- Xun, C., Zeng, X. & Wang, X., 2007. Microscrew anchorage in skeletal anterior open-bite treatment. *The Angle Orthodontist* 77, pp. 47–56.
- Zimmerman, J.B., 1989. Orofacial myofunctional therapy for bilateral tongue posture and tongue thrust associated with open bite: a case report. *International Journal Orofacial Myology* 15, pp. 5–9.

8

Orthodontics and Temporomandibular Joint (TMJ) Disorders

Friederike Luther¹, BDS (Hons), FDSRCS, DOrth RCS, MOrth RCS, MSc, PhD, FHEA, **Fraser McDonald**², BDS, MSc, PhD, FDSRCS, FFDRCSI

¹Department of Orthodontics, Leeds Dental Institute, University of Leeds, Leeds, UK

²Senior Lecturer and Honorary Consultant Orthodontist, Department of Orthodontics, King's College London Dental Institute, King's College, London, UK

Background

The temporomandibular joint (TMJ) is the joint between the lower jaw and the base of the skull. TMJ disorders (TMDs) refer to a group of disorders with symptoms that include pain, clicking, grating in the jaw joint, and problems with chewing or opening the jaw. This condition can be known by a variety of names, including craniomandibular disorders (CMDs), and is a frequent cause of facial pain problems (Dworkin & LeResche 1992). A positive relationship between occlusal factors (the way the teeth bite together) and TMD has been suggested (Ramfjord 1961). However, the term TMD may eventually be discarded as we come to understand the underlying pathophysiology of this disorder, especially with respect to chronic musculoskeletal pain. Prevalence studies have reported approximately 75% of the population has at least one sign of joint dysfunction (abnormal

jaw movement, joint noises, tenderness on palpation, etc.) and approximately 33% have at least one symptom (facial pain, joint pain, etc.) (Rugh & Solberg 1985; Schiffman & Friction 1988). It is a significant finding that in all studies except one (Talaat, El-Dibany & El-Garf 1986) females are affected more than males. There are many suggested causes of TMD, although it is generally accepted that TMD covers a significant number of conditions but with common symptoms. Various theories have been put forward that relate the occlusion (bite of teeth), trauma, and stress to TMD (Bell 1986). It is suggested that the common signs and symptoms of TMD—pain, joint sounds (clicking, grating), and limited or asymmetrical jaw movement—may have an effect on health and quality of life, which in turn can lead to anxiety.

A developing view of TMD is linked to that of low back pain. The use of the word *psychogenic* suggests there is no known physical cause. However a bio-psychosocial model is developing as the most heuristic approach to chronic pain (Gatchel et al. 2007). This has been related to TMD (Suvinen et al. 2005), whereby the interaction of basic neuroscience processes of pain (the *bio* of biopsychosocial) with psychosocial factors or the interaction of psychological and social factors with the processing of information in the central nervous system influence health. The causation related to gender predisposition may be associated with genetic variations of pain perception, although this is yet to be defined (Tedeager & Lötsch 2009). There is some data that link pain to the circulating hormones. One study in particular, although with a limited sample size, considered low levels of estrogen relating to highest levels of pain (although increased levels of pain may also be associated with the most rapid periods of change of estrogen levels) (LeResche et al. 2003).

Treatment options for TMD include reassurance (patient education, self-care, and behavior therapy); physiotherapy (such as ultrasound, megapulse, acupuncture, short-wave diathermy laser, heat exercises, and biofeedback); splint therapy, drug therapy; occlusal adjustment; surgical intervention; and combined treatment. Acupuncture has been a particular treatment modality favored by List and colleagues (1993), and there are numerous articles in the literature relation to this topic. It is, however, outside the remit of this review. Certain authors consider conservative, “low-tech” treatment, as success rates from invasive treatment do not produce a better result (Stohler & Zarb 1999). Furthermore, some authors actually debate the need for treatment: LeResche (2001) suggested only 10% of the population aged over 18 are likely to have symptoms and McNeill (1997) and Okeson (1996), using other authors’ data, estimated that 3.6%–7.0% actually need treatment.

Occlusal adjustment (OA) is the selective adjustment of the biting surface of the teeth by grinding the enamel (outer layer of the tooth) so that the upper and lower teeth fit together (the intercuspal position) harmoniously and is the subject of another Cochrane review (Koh & Robinson 2003). The summary finding, however, is that there is no consistent data to support this permanent change in the shape of the occlusal surface of the teeth to treat TMD. Cochrane reviews of other treatments (e.g., splint therapy or surgery) are also underway or are published. It is not clear if malocclusion has a causal role in TMD. However, orthodontic treatment has been used in studies to prevent TMD. There are ethical and clinical implications if orthodontic treatment is found to be ineffective in preventing or initiating TMD.

As all the muscles associated with chewing may be affected by the disorder, the pain is often felt away from the joint, so the term CMD has also been described (Dworkin, LeResche & DeRouen 1990). Okeson (1997) described TMD as a collective term includ-

ing a number of clinical problems that involve the chewing muscles, the TMJ and associated structures, or both. Psychosocial factors play a major part in the causes of TMD, and by treating/managing the factors associated with stress and anxiety of the patient, the symptoms and signs of TMD can often be reduced or stopped (Greene 1995).

There is a distinct profile of the types of patients affected by TMD, and the number of people affected by the condition increases with age. It is far more common in females to the point that only females are reported in some studies, with no record of the incidence or prevalence in males affected (Landi et al. 2004; Miller, Mancl & Critchlow 2005). In a report by Lipton, Ship & Larach-Robinson (1993), TMJ pain was reported by 5.5% of the population in a survey of 45,711 U.S. households. Previous studies have indicated that approximately 75% of patients have at least one sign of joint dysfunction (abnormal jaw movement, joint noises, tenderness on palpation, etc.), and approximately 33% have at least one symptom of TMD (facial pain, joint pain, etc.).

There is a significant degree of controversy regarding the relationship of TMD and orthodontic treatment (Luther 1998a, 1998b). The use of orthodontic appliances to correct the alignment and vertical relationships of teeth has small yet significant risks: an increase in plaque buildup, leading to an increase in oral and dental disease; a reduction of bone support to the teeth; and possible root resorption (Ireland & McDonald 2003). Included in the possible risks of orthodontic treatment is the concern related to the development of TMD. There are many studies that have examined the interrelationships of the occlusion (malocclusion) and the development of TMD. The reports appear to relate to specific issues:

1. Is the malocclusion, without treatment, related to the development of TMD?
The nature of the psychosocial profile of the population studied can vary, and as a consequence, the studies of two groups from differing areas in the same country may nullify each other. In the study by Sadowsky and Polson (1984), groups in both Illinois and New York are examined. In this paper, although there is a comparison between the treated and untreated groups of the socio-economic background and ethnicities within each study, it is not reported if the two studies were compared in this respect. A 20-year follow-up using questionnaires to self-report the signs and symptoms has demonstrated that while several malocclusion traits were consistent for patients with TMD, there were no strong correlations between them, and as such, screening of malocclusion on the basis of identifying those at risk of TMD was not worthwhile (Helm & Petersen 1989).
2. Is orthodontic treatment capable of improving the signs or symptoms of TMD?
A study examining adolescent girls undergoing treatment showed that in the treated group there was a significantly reduced prevalence of muscular signs after treatment but that clicking, a symptom often identified, increased in both the treated, untreated, and normal groups over the 2 years of observation (Henrikson, Nilner & Kurol 1999, 2000).
3. Does orthodontic treatment predispose to the development of TMD in later life? Long-term follow-up studies are clearly difficult but have been undertaken with some robust data acquisition. One group of researchers has followed patients until 30 years of age. They identified no link between orthodontic

treatment acting as either a preventative measure or a significant cause of TMD. They did identify significant associations with TMD and general health and psychosocial well-being, as well as neuroticism and self-esteem measures (Mohlin et al. 2004). Another group has reported several papers on the longitudinal follow-up of patients for 20 years. The overall conclusion initially was that although the patients who had undergone orthodontic treatment had a reduced dysfunction index (Egermark & Thilander 1992), further follow-up indicated that orthodontic care did not predispose to the development of TMD in later life (Egermark, Magnusson & Carlsson 2003, Egermark, Carlsson & Magnusson 2005).

Many of the studies, although identifying small associations, fail to isolate a single unique aspect that can either refute or support the association of orthodontic treatment to TMD, presumably because of the diffuse nature of TMD. Thus, it appears that to date the ideal study has not yet been undertaken to assess this, and while there are small but significant risks involved in the use of orthodontic appliances, especially the more complex appliances, the use of a technique without data to support it is not considered appropriate in contemporary health care. This can be especially so if the clinicians are poorly trained in the use of such appliances. Furthermore, the use of any treatment may inappropriately raise patient expectations as well as waste valuable health-care resources (in as much as no patient benefit will be predictably and reliably achieved).

The prognosis of TMD, due to the multifactorial nature of the condition, is difficult to establish. A long-term follow-up of over 30 years (deLeeuw, Boering & Stegenga 1994) established the chronic nature of such a condition.

The working hypothesis appears to be that if the teeth bite incorrectly in the form of a malocclusion, this can then apply a restriction to the function of the TMJ or, worse still, predispose it to future pathological deterioration. By correcting the alignment and arrangement of the teeth, the TMJ will remodel to the overriding new functional needs, thus treating any disease processes or malfunction of joint integrity and allowing normal function to continue unabated for the life of the patient (Moss & Salentijn 1969). The subject can be further subdivided into two aspects or questions: Does orthodontic treatment predispose to later development or worsening of TMD? Does orthodontic treatment permanently and consistently improve the immediate signs and symptoms of TMD?

Objectives

The following primary null hypothesis was tested:

Orthodontic treatment does not treat or prevent symptoms of TMD.

Specifically, the review addressed the hypotheses of no difference between orthodontic treatment and control for TMD for the following outcomes where data were available:

- overall symptoms
- relief of headache
- patient quality of life

Methods

Criteria for Considering Studies for this Review

Types of Studies

All randomized controlled trials (RCTs), including quasi-randomized clinical trials assessing orthodontic treatment in TMD, were included.

Types of Participants

Adults aged 18 years or older with clinically diagnosed TMD were included. There were no age restrictions for prevention trials provided the follow-up period extended into adulthood.

The list of symptoms (Austin & Pertes 1995) included the following:

- The occurrence of recurrent headache (equal or more than two episodes a month).
- Pain in the jaws, face, throat, neck, shoulders, or back.
- Ear symptoms (includes tinnitus, stuffiness, diminished hearing, or pain).
- Pain in the temporomandibular joint (TMJ) at rest and during chewing.
- Day and night time grinding or clenching.
- Vertigo.
- Stiffness in jaws.
- Difficulties in swallowing.
- Globus symptoms (associated with choking sensations or soreness of the throat).
- Joint sounds (including clicking and grating).
- Spontaneous luxation or locking of the jaws.

The list of signs included the following:

- Palpatory tenderness on either side of the masticatory muscles.
- Joint sounds during jaw movements, elicited by auscultation.
- Distinction between opening and closing clicks, crepitations, and reciprocal clicking (as with previous Cochrane studies of this disorder).
- Tenderness during jaw movements.
- Deviation of the mandible on opening and closing.
- Reduced mandibular range of motion.
- Presence of occlusal interference in retruded, protruded, and medio- and latero-trusion positions of the mandible.
- Wear facets.

TMD was required to be clinically absent at baseline in studies on prevention, and any signs or symptoms associated with pain of dental origin were excluded.

Types of Interventions

The treatment group received appliances that could induce stable orthodontic tooth movement by way of wear for a significant period of time which would induce permanent changes in tooth position. Therefore, patients receiving splints for 8–12 weeks, while capable of moving teeth during the short term, would not be considered.

The control groups received no treatment, placebo, or reassurance.

Studies in which splints had been used prior to placement of orthodontic appliances were excluded.

Types of Outcome Measures

Primary Outcomes The main outcomes considered were overall symptoms, pain, and headache. Relief from symptoms was assessed using global measures of symptoms. Data on pain were recorded according to frequency, severity, or duration. Where possible, data for the frequency, severity, and duration of pain were aggregated.

Similarly, data on headache were recorded according to frequency, severity, or duration. Where possible, data for the frequency, severity, and duration of pain were also aggregated.

The interval required for outcome measurement was at least 6 months after the intervention.

Secondary Outcomes Limitation of movement. Other signs were ignored because they are neither unique to the disease nor associated with the progression or outcomes of TMD.

Search Methods for Identification of Studies

The subject search used a combination of controlled vocabulary and free text terms based on the search strategy developed for MEDLINE. The search was combined with the Cochrane Highly Sensitive Search Strategy for identifying randomized controlled trials as referenced in Chapter 6.4.11.1 and detailed in box 6.4.c of *The Cochrane Handbook for Systematic Reviews of Interventions* Version 5.0.1 (updated September 2008).

From Electronic Searches

Databases to Be Searched The following databases were searched: The Cochrane Oral Health Group Trials Register (to present), The Central Register of Controlled Clinical Trials (to Issue 1, 2009), MEDLINE 1950–October 23, 2009, EMBASE 1980–October 23, 2009.

Language The search identified all relevant studies irrespective of language. Every attempt was made for non-English papers to be translated.

Checking Reference Lists The reference lists of all relevant trials obtained were checked, along with the reference lists of relevant review articles. In addition, reference lists from

prosthetic dentistry textbooks on temporomandibular disorders and splint therapy were also checked.

Hand Searching The following journals were identified as being important to hand search for this review for the period 1939 to present:

- *Acta Odontologica Scandinavica* (1939–October 2009)
- *Journal of the American Dental Association* (1966–October 2009)
- *Journal of Oral Rehabilitation* (1974–October 2009)
- *Journal of Craniomandibular Practice* (1986–October 2009)
- *Journal of Oral and Maxillofacial Surgery* (1982–October 2009)

The review authors examined these journals following the guidance of the *Training Manual for Handsearchers* (2002).

Personal Contact A comprehensive list of relevant articles, along with the criteria for the review, was included in a letter that was sent to the first author of each paper asking for any unpublished, relevant studies not included in the list. Copies of the same letter were also sent to other experts in the field of TMD or others with an interest in the area. In addition, evidence in the form of scientific articles offered in support of legal cases was also examined both in the form of material previously submitted and by contacting the legal experts who support such protocols. The British Orthodontic Society was contacted for any unpublished data on this subject as were with the authors of information leaflets of the British Orthodontic Society in which TMD was discussed.

Unpublished Studies

Conference proceedings and abstracts were examined but did not provide data appropriate for consideration.

Data Collection and Analysis

Study Selection

The title, abstract, and key words of identified studies were screened independently by all reviewers for relevance to the systematic review. Studies meeting the inclusion criteria were retrieved as complete articles. Those with randomized and quasi-randomized controlled design, participants with diagnoses (TMD) confirmed clinically, occlusal adjustment and control treatment specified, and the required outcome variables reported were included. The term *quasi-randomized studies* followed the definition in the *Oral Health Review Group Journal Hand-searchers' Manual* (2002) and are studies in which the method of allocation was known but not considered strictly random. Non-randomized trials were excluded.

The Cochrane Oral Health Group's statistical guidelines were followed, and risk ratio values were to be calculated along with 95% confidence intervals for binary data. Mean differences and 95% confidence intervals were to be used for continuous data. Categorical data were to be converted to binary outcomes, for example, cured/not cured, improved/not

improved, with sensitivity analyses of the “same” group to give best- and worst-case scenarios. The studies were grouped according to treatment type and duration of follow-up.

Data Extraction

All reviewers independently extracted data, if appropriate, from the included studies to a predesigned data collection form. The data extraction form considered bibliographic details, details of the study setting, characteristics of the study population, frequency and course of the interventions, baseline and outcome measures, etc.

There were no uncertainties on data extraction. Authors of the original studies were consulted by mail to obtain more information about any of the published studies to determine if there were data that could be extracted.

All review authors independently assessed the risk of bias of all included studies.

Data Synthesis

Unfortunately there was no data to consolidate and so it was not possible to consider any statistical evaluations.

Results

Description of Studies

Characteristics of Trial Setting and Investigators

The searches identified 265 records from all databases. Initial screening of the abstract and title by all reviewers identified 52 articles. The full article was then retrieved, and of these articles, three demonstrated any data that might be of value with respect to TMD and orthodontics. However, the study designs were so fundamentally different in terms of the groups, selection, and methods, that the data could not be compared.

The majority of trials were excluded as they did not include subject matter relevant to the topic ($n = 21$); the remainder included splints ($n = 18$), no control groups for comparison ($n = 5$), only assessed symptoms and signs but did not include orthodontic care ($n = 3$), and surgical intervention ($n = 1$). The remaining studies, although not achieving the correct level for inclusion of data, identified some noteworthy findings. Three articles (Keeling et al. 1995; Gianelly et al. 1988; Sonnesen & Svensson 2008) considered a tenuous link with the level of overbite; two studies examined joint function with imaging, although one did not include orthodontics (Piancino et al. 2008), and the other examined the findings of children with clinical symptoms (Keeling et al. 1995).

Characteristics of Participants

Fifteen trials recruited patients with symptoms of TMD for treatment but followed them in very disparate ways.

Characteristics of Interventions

There were three groups of trials for assessment. One group considered the intervention in treating patients with TMD. The second group considered a cross-sectional study of

patients who had also had orthodontic treatment, and the final group of trials considered the prevention of TMD using orthodontic treatment.

All of the treatment trials provided a clear description of the type and duration of intervention for both the test and control group (Keeling et al. 1995; Gavakos & Witt 1991). Only one provided significant numbers for a control group (Okinawa, Schmelzeisen & Vogt 1995), but they did not follow up this group.

Characteristics of Outcome Measures

None of the trials reported both signs and symptoms of TMD (Austin & Pertes 1995). There was significant variation between the trials in the assessment of symptoms for TMD. There was variation in the type of measurement used for the main outcomes, as well. Several trials used a visual analog scale for pain and the presence or absence of headache and globus, whereas others used questionnaires and some used the Helkimo index (Egermark, Magnusson & Carlsson 2003; Egermark, Carlsson & Magnusson 2005; Gavakos & Witt 1991; Olsson & Lindqvist 2003, for example).

An additional clinical outcome reported was the range of mandibular movement. There was limited data on psychosocial outcomes, costs, or quality of life in any of the trials. There were no reports of adverse reactions.

Approval from an ethical committee was present in only two studies (Pedroni, De Oliveira & Guartini 2003; Truelove, Huggins & Mancil 2006). Although identified through our search parameters, these studies had no relevance to this review.

Two trials (Milosevic & Samuels 1998, 2000) had a peer-reviewed grant available locally within the country, whereas the remaining trials did not report funding.

In one trial (Bergström, List & Magnusson 2008), for example, the total range of participants was considered, but the actual standard deviation, error, or confidence intervals were not reported. There were no major differences in the other baseline characteristics.

The generation of allocation was adequate in four trials (Ekberg, Vallon & Nilner 2002; Franco et al. 2002; Minakuchi, Kuboki & Matsuka 2001; Truelove et al. 2006); inadequate in two trials (Gianelly et al. 1988; Keeling et al. 1995); and unclear in two trials (Turk, Zaki & Rudy 1993; Piancino et al. 2008). In many trials there was retrospective analysis of patients, clearly including a significant degree of bias into the study designs (Gavakos & Witt 1991). In all studies, the numbers of participants examined was not derived from *a priori* power calculations. Some studies reported numbers that were too small to consider an extensive case series (Kuboki et al. 1999).

Performance Bias

All the trials were performed by dentists trained in assessment of TMD symptoms and signs, and the training of such assessment was standardized. Adjustment for confounders was either absent or unclear in all trials.

The concealment of allocation was inadequate for all trials.

Effects of Interventions

The majority of trials were excluded as they did not include subject matter relevant to the topic ($n = 21$); the remainder included splints ($n = 18$), no control groups for comparison ($n = 5$), only assessed symptoms and signs but no orthodontic care ($n = 3$), and surgical

intervention ($n = 1$). The remaining studies identified some noteworthy findings, although they did not provide data that supported aggregation and further analysis. In two articles (Gianelly et al. 1988; Sonnesen & Svensson 2008), a tenuous link with the level of overbite was considered; two studies examined joint function with imaging. Although one did not include orthodontic treatment (Piancino et al. 2008), the other examined the findings of children with clinical symptoms (Keeling et al. 1995).

In some instances there was inadequate reporting of symptoms (Franco et al. 2002).

There were no data on psychosocial outcomes, costs, and quality of life.

Discussion

There is an absence of evidence that orthodontic treatment treats or prevents temporomandibular disorders (TMDs). There are no trials or studies that reach the threshold required to support the concepts of orthodontic treatment relating to TMD. It is important to distinguish between absence of evidence and evidence of absence. There may not be evidence of an effect because there are no data regarding the effectiveness of orthodontic treatment for TMD.

Some data from four studies did lead to a degree of understanding that could assist in delivering care for patients. One of the more robust (although insufficient for data analysis) studies (Conti et al. 2003) assessed 200 patients divided into four groups, depending on the malocclusion type. While the data lacked a control group, there was an association identified that linked parafunctional habits such as grinding, but not orthodontic treatment, to TMD.

In a further study (Franco et al. 2002), Class II division 1 malocclusions were evaluated with a control group and a Frankel II therapy group (Frankel appliances are a group of appliances that work by changing the environment of the lips and the cheeks and in so doing apply forces to move the teeth). The issue that negates the value of this study as one to be considered is that the control group comprised patients observed over an 18-month period before treatment was commenced; this does not provide a robust control group. The disc position was assessed using magnetic resonance imaging (MRI), and the outcome was that orthodontic therapy did not affect disc position. A significant omission was that symptoms of TMD were not assessed, only disc position. The recommendations derived from this study, therefore, are that ethical approval is required, a true and absolute control group needs to be considered alongside the study group, and symptoms and signs should be incorporated with the MRI views.

Keeling et al. (1995) assessed a robust number of participants (although there was no evaluation at the outset as to how many should be considered). In this study, 60 patients were treated with a functional appliance, 60 patients were observed, and 60 patients were treated with headgear and a bite plane. The patients were evaluated for TMD prior to treatment and then assessed by examiners who were blinded to the type of treatment provided to the patient. The initial study began in 1990 when ethical approval was not as stringent as in 2009; the obtaining of informed consent is detailed. The data appeared to indicate that age was the most significant factor relating to developing TMD; in addition, patients that began the study with TMD were seven times more likely to have these symptoms at follow-up. Within the study there was no reporting of intention to treat or indication of any dropouts from the original cohort over and above those excluded on the basis of the study protocol. However, this is not a study that provides any data for this review.

Class III malocclusions were evaluated in one particular study (Gavakos & Witt 1991) in which different treatment modalities were identified for assessing a type of jaw relationship thought to lead to TMD. There were several types of appliance systems, with treatment commencing in the mixed dentition phase and continuing until growth was complete. These treatment techniques included a functional appliance, 27 patients further treated with fixed appliances, and 3 patients treated with a reverse headgear. There was a clear description of the gender and age of the patients at commencement of the study. There was no assessment of the symptoms of TMD prior to commencement of the orthodontic treatment, although the patients were assessed using the Helkimo index and the clinical dysfunction index. A third evaluation used the occlusal state determined by clinical investigation of the number of teeth, the number of teeth in occlusion, occlusal interferences during movement from retruded contact position to the intercuspatal position, and articulation interferences during protrusion and lateral movements. None were correlated to symptoms of TMD. Surgical patients were also included. There were no reported differences in the groups evaluated, but the study was retrospective.

Egermark followed a cohort of patients who had orthodontic care between 1981 and 1983 and laudably followed up the patients 20 years later (Egermark, Magnusson & Carlsson 2003, Egermark, Carlsson & Magnusson 2005). The studies used a questionnaire and calculated the Helkimo index for evaluation of TMD. One of the conclusions was that there was no statistically significant difference in the prevalence of TMD in patients who had received orthodontic treatment when compared with those who hadn't received active orthodontic intervention. The numbers in the 35-year-old group were significantly reduced. One hundred two patients had been identified, but the actual types of orthodontic treatment were recorded from the patient history (patient affirmed receipt of some kind of orthodontic treatment in childhood) (Egermark, Magnusson & Carlsson 2003). Clearly, the varied nature of the treatment mechanics could not be recorded precisely on the basis of the patient's recollection. The groups were further subdivided as the level of the care provided differed, varying between specialist-level care and that provided by general dental practitioners; it was also unclear as to the number of individuals delivering the care. In the latter study (Egermark, Carlsson & Magnusson 2005), a total of 50 subjects (27 males and 23 females) were identified but were further subdivided due to the varied nature of the malocclusions that had been treated. The overall incidence of manifest TMD that required treatment was 1%, and the study did not identify a significant increase with those patients who had undergone orthodontic treatment.

A major study has been published from Groningen, the Netherlands (Dibbets & van der Weele 1987, 1989, 1992). This study has produced a significant amount of data examining orthodontic treatment and TMD. The final report (Dibbets & van der Weele 1992) looked at patients 20 years after treatment; the treatment was divided into functional appliances, Begg treatment, and chin cap treatment. There was no control group. In addition, the cases were analyzed with regard to extractions; the three groups were nonextraction, extraction of four premolars, and all other types of extractions. By evaluation of the participants using frequencies and the chi-squared statistic, it was apparent that neither the type of treatment nor extractions predisposed to the development of TMD after 20 years of observation (Dibbets & van der Weele 1992).

The study by Minakuchi, Kuboki & Matsuka (2001), although not using orthodontics as one of the treatment modalities, was noteworthy in terms of principle within the remit of TMD treatment. In this study the authors identified anterior disc displacement without reduction. The patients were recruited to the study, which occurred during 1997 and 1998,

and the study had institutional review and approval from the appropriate committee. The 69 patients were allocated to one of three groups of patients—no treatment, self-care, and nonspecific anti-inflammatory agents and an occlusal appliance—and observed over an 8-week period. The 8-week period of assessment was deemed by the authors of this Cochrane review to be insufficient to produce stable orthodontic tooth movement. There were robust inclusion criteria reported, and the initial group of patients consisted of 269 patients, eventually leading to a recruitment of the 69 participants. There was clear and precise recording of the reasons for noninclusion. The final group of participants had clear reporting of the male/female allocation (reflecting the female preponderance for the condition, 7 males and 62 females) and the age of the cohort, together with the standard deviation of the patients (34.0 ± 15.4). All patients had MRI images and had an initial observation period following a full explanation of the condition and diagnosis. Standardized visual analog scales were used to assess the symptoms at the start of treatment and throughout the observation period. The conclusions from this study were that the treatment required for TMD was minimal and that there was no difference between the different treatment approaches and the control group.

One apparent issue relates to the recommendation that in some instances patients should not have any active treatment as this will not alleviate the signs and symptoms.

There are concerns regarding the validity and reliability of the criteria used in all the trials. Inaccurate and inconsistent diagnosis of TMD causes misleading reporting of TMD and incomparability of results with other trials.

Recommendations for future research include the following:

1. Ethical approval and consent must be obtained.
2. Studies must report the odds ratio, relative risk, relative risk reduction, absolute risk reduction, or weighted mean difference and associated 95% confidence intervals where appropriate.
3. The studies must be well controlled with respect to bias, and blinding is essential.
4. Data should be reported for psychosocial outcomes, costs, and quality of life.
5. Standardized diagnostic criteria for TMD should be used.
6. Standardized outcome measures for evaluating treatments of TMD should be used.
7. The study should report side effects, especially if they were directly related to the intervention.
8. Intra- or extra-examiner variability should be reported where appropriate.
9. Future research should use samples of adequate size based on power calculations. The existing trials should be used as the basis of such power calculations.

To date, to our knowledge, there has never been a satisfactory evaluation of orthodontics with respect to TMD. It is believed that the most robust study would require the recruitment of participants with diagnosed TMD, allocation to groups relating to the malocclusion (or not), and treatment with either active orthodontic intervention or splints.

Conclusions

There is no evidence to support or refute orthodontic therapy for the treatment of TMD. In addition, no data identifies a link between active orthodontic intervention and the causation of TMD. Based on the lack of data, orthodontic treatment cannot be recommended for the treatment or prevention of TMD. Patients attending with symptoms of TMD prior to orthodontic treatment should be counseled appropriately with regard to the possibilities of the progression of the disorder, that is, it may worsen, stay the same, or improve. The apparent random nature of the progression of such a disease process demonstrates the need for clear, unambiguous informed consent. The views of Stohler and Zarb (1999), aiming for the simpler solutions, seem to be the most sensible in light of current data.

An issue that developed during this study occurred during the screening of papers and identification of the data. In many instances, the quality of editorial stringency applied to abstracts (structured or unstructured) was poor and failed to ensure that the abstract reflected the body of the text of the article.

1. Additional well-designed clinical trials are needed to elucidate whether there is any benefit from orthodontic treatment of TMD.
2. Consideration needs to be given to developing valid and standardized diagnostic criteria for TMD.
3. Consideration needs to be given to standardized outcome measurements for evaluating interventions for TMD.
4. Guidelines, produced by the CONSORT Group, have been published for reporting of randomized controlled trials in the medical literature (Moher et al. 2010). The use of such guidelines would improve the quality of trials and reports of TMD management.

Acknowledgments

Thanks go to Emma Tavender, Review Group Coordinator, and Luisa Fernandez, Managing Editor, at the Cochrane Oral Health Group for their help with the administration and support of the review; Jayne Harrison for her help in the editorial process; and Sylvia Bickley and Anne Littlewood for carrying out the searches for the review.

We would also like to thank those who have provided comments and editorial input into this review. This chapter is based on a Cochrane Systematic Review. The original version is: Luther F, Layton S, McDonald F. Orthodontics for treating temporomandibular joint (TMJ) disorders. Cochrane Database of Systematic Reviews 2010, Issue 10. Art. No.: CD006541. DOI: 10.1002/14651858.CD006541.pub2 (<http://dx.doi.org/10.1002/14651858.CD006541>). This review is published as a Cochrane Review in the Cochrane Database of Systematic Reviews 2010, Issue 10. Cochrane Reviews are regularly updated as new evidence emerges and in response to comments and criticisms, and the Cochrane Database of Systematic Reviews should be consulted for the most recent version of the review.

References

- Austin, D.G. & Pertes, R.A., 1995. *Examination of the TMD patient*. Chicago: Quintessence Publishing.
- Bell, W.E., 1986. Classification of temporomandibular disorders. In: Bell, W.E., ed. *Temporomandibular disorders. Classification, diagnosis, management*. Chicago: Year Book Medical Publishers, pp. 172–214.
- Bergström, I., List, T. & Magnusson, T., 2008. A follow-up study of subjective symptoms of temporomandibular disorders in patients who received acupuncture and/or interocclusal appliance therapy 18–20 years earlier. *Acta Odontologica Scandinavica* 66, pp. 88–92.
- Conti, A., Freitas, M., Conti, P. et al., 2003. Relationship between signs and symptoms of temporomandibular disorders and orthodontic treatment: a cross-sectional study. *The Angle Orthodontist* 73, pp. 411–417.
- deLeeuw, R., Boering, G. & Stegenga, B., 1994. Clinical signs of TMJ osteoarthritis and internal derangement 30 years after nonsurgical treatment. *Journal of Orofacial Pain* 8, pp. 18–24.
- Dibbets, J.M.H. & van der Weele, L.T., 1987. Treatment in relation to symptoms attributed to dysfunction of the temporomandibular joint: a 10-year report of the University of Groningen study. *American Journal of Orthodontics and Dentofacial Orthopedics* 91, pp. 193–199.
- Dibbets, J.M.H. & van der Weele, L.T., 1989. Prevalence of TMJ symptoms and x-ray findings. *European Journal of Orthodontics* 11, pp. 31–36.
- Dibbets, J.M.H. & van der Weele, L.T., 1992. Long-term effects of orthodontic treatment, including extraction, on signs and symptoms attributed to CMD. *European Journal of Orthodontics* 14, pp. 16–20.
- Dworkin, S.F., LeResche, L. & DeRouen, T., 1990. Assessing clinical signs of temporomandibular disorders: reliability of clinical examiners. *The Journal of Prosthetic Dentistry* 63, pp. 574–579.
- Dworkin, S.F. & LeResche, L., 1992. Research diagnostic criteria for temporomandibular disorders: review, criteria, examinations and specifications, critique. *Journal of Craniomandibular Disorders* 6, pp. 301–355.
- Egermark, I. & Thilander, B., 1992. Craniomandibular disorders with special reference to orthodontic treatment: an evaluation from childhood to adulthood. *American Journal of Orthodontics and Dentofacial Orthopedics* 101, pp. 28–34.
- Egermark, I., Magnusson, T. & Carlsson, G.E., 2003. A 20-year follow-up of signs and symptoms of temporomandibular disorders and malocclusions in subjects with and without orthodontic treatment in childhood. *The Angle Orthodontist* 73, pp. 109–115.
- Egermark, I., Carlsson, G.E. & Magnusson, T., 2005. A prospective long-term study of signs and symptoms of temporomandibular disorders in patients who received orthodontic treatment in childhood. *The Angle Orthodontist* 75, pp. 645–650.
- Ekberg, E., Vallon, D. & Nilner, M., 2002. Treatment outcome of headache after occlusal appliance therapy in a randomised controlled trial among patients with temporomandibular disorders of mainly arthrogenous origin. *Swedish Dental Journal* 26, pp. 115–124.
- Franco, A.A., Yamashita, H.K., Lederman, H.M. et al., 2002. Fränkel appliance therapy and the temporomandibular disc: a prospective magnetic resonance imaging study. *American Journal of Orthodontics and Dentofacial Orthopedics* 121, pp. 447–457.
- Gatchel, R.J., Peng, Y.B., Peters, M.L. et al., 2007. The biopsychosocial approach to chronic pain: scientific advances and future directions. *Psychological Bulletin* 133, pp. 581–624.
- Gavakos, K. & Witt, E., 1991. The functional status of orthodontically treated prognathic patients. *European Journal of Orthodontics* 13, pp. 124–128.
- Gianelly, A.A., Hughes, H.M., Wohlgemuth, P. et al., 1988. Condylar position and extraction treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 93, pp. 201–205.
- Greene, C.S., 1995. Etiology of temporomandibular disorders. *Seminars in Orthodontics* 1, pp. 222–228.

- Helm, S. & Petersen, P.E., 1989. Mandibular dysfunction in adulthood in relation to morphologic malocclusion at adolescence. *Acta Odontologica Scandinavica* 47, pp. 307–314.
- Henrikson, T., Nilner, M. & Kurol, J., 1999. Symptoms and signs of temporomandibular disorders before, during and after orthodontic treatment. *Swedish Dental Journal* 23, pp. 193–207.
- Henrikson, T., Nilner, M. & Kurol, J., 2000. Signs of temporomandibular disorders in girls receiving orthodontic treatment. A prospective and longitudinal comparison with untreated Class II malocclusions and normal occlusion subjects. *European Journal of Orthodontics* 22, pp. 271–281.
- Ireland, A.J. & McDonald, F., 2003. *The orthodontic patient: treatment and biomechanics*. Oxford: Oxford University Press.
- Keeling, S.D., Garvan, C.W., King, G.J. et al., 1995. Temporomandibular disorders after early Class II treatment with bionators and headgears: results from a randomized controlled trial. *Seminars in Orthodontics* 1, pp. 149–165.
- Koh, H. & Robinson, P.G., 2003. Occlusal adjustment for treating and preventing temporomandibular joint disorders. *Cochrane Database of Systematic Reviews* 1, DOI 10.1002/14651858.CD003812.
- Kuboki, T., Takenami, Y., Orsini, M.G. et al., 1999. Effect of occlusal appliances and clenching on the internally deranged TMJ space. *Journal of Orofacial Pain* 13, pp. 38–48.
- Landi, N., Manfredini, D., Tognini, F. et al., 2004. Quantification of the relative risk of multiple occlusal variables for muscle disorders of the stomatognathic system. *Journal of Prosthetic Dentistry* 92, pp. 190–195.
- LeResche, L., 2001. Epidemiology of orofacial pain, section I. The clinical problem and epidemiology. In: Lund, J.P., Lavigne, G.J., Dubner, R. et al., eds. *Orofacial Pain. From basic science to clinical management. The transfer of knowledge in pain research to education*. Chicago: Quintessence Publishing, pp. 15–25.
- LeResche, I., Mancl, L., Sherman, J.J. et al., 2003. Changes in temporomandibular pain and other symptoms across the menstrual cycle. *Pain* 106, pp. 253–261.
- Lipton, J.A., Ship, J.A. & Larach-Robinson, D., 1993. Estimated prevalence and distribution of reported orofacial pain in the United States. *Journal of the American Dental Association* 124, pp. 115–121.
- List, T., Helkimo, M. & Karlsson R., 1993. Pressure pain thresholds in patients with craniomandibular disorders before and after treatment with acupuncture and occlusal splint therapy: a controlled clinical study. *Journal of Orofacial Pain* 7, pp. 275–282.
- Luther, F., 1998a. Orthodontics and the temporomandibular joint: where are we now? Part 1. Orthodontic treatment and temporomandibular disorders. *The Angle Orthodontist* 68, 295–304.
- Luther, F., 1998b. Orthodontics and the temporomandibular joint: where are we now? Part 2. Functional occlusion, malocclusion, and TMD. *The Angle Orthodontist* 68, pp. 305–318.
- McNeill, C., 1997. History and evolution of TMD concepts. *Oral Surgery, Oral Medicine, Oral Pathology* 83, pp. 51–60.
- Miller, J.R., Mancl, L. & Critchlow, C., 2005. Severe retrognathia as a risk factor for recent onset painful TMJ disorders among adult females. *Journal of Orthodontics* 32, pp. 249–256.
- Milosevic, A. & Samuels, R.H.A., 1998. Functional occlusion after fixed appliance orthodontic treatment, a UK three-centre study. *European Journal of Orthodontics* 20, pp. 561–568.
- Milosevic, A. & Samuels, R.H.A., 2000. The post-orthodontic prevalence of temporomandibular disorder and functional occlusion contacts in surgical and non-surgical cases. *Journal of Oral Rehabilitation* 27, pp. 142–148.
- Minakuchi, H., Kuboki, T. & Matsuka, Y., 2001. A randomized controlled evaluation of non-surgical treatments for temporomandibular joint anterior disk displacement without reduction. *Journal of Dental Research* 80, pp. 924–928.
- Moher, D., Hopewell, S., Schulz, K.F. et al. 2010. CONSORT 2010. Explanation and elaboration: updated guidelines for reporting parallel group randomised trials. *British Medical Journal* 340, pp. c869. DOI 10.1136/bmj.c869.
- Mohlin, B.O., Derweduwen, K., Pilley, R. et al., 2004. Malocclusion and temporomandibular disorder: a comparison of adolescents with moderate to severe dysfunction with those without signs

- and symptoms of temporomandibular disorder and their further development to 30 years of age. *The Angle Orthodontist* 74, pp. 319–327.
- Moss, M.L. & Salentijn, L., 1969. The primary role of functional matrices in facial growth. *American Journal of Orthodontics* 55, pp. 566–77.
- Okeson, J.P., 1996. Differential diagnosis and management considerations of temporomandibular disorders. In: Okeson, J.P., ed. *Orofacial pain, guidelines for assessment, diagnosis and management*. Chicago: Quintessence Publishing, pp. 113–184.
- Okeson, J.P., 1997. Current terminology and diagnostic classification schemes. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* 83, pp. 61–64.
- Okinawa, K., Schmelzeisen, R. & Vogt, S., 1995. Alteration of temporomandibular joint symptoms after orthognathic surgery, comparison with healthy volunteers. *Journal of Oral and Maxillofacial Surgery* 53, pp. 117–121.
- Olsson, M. & Lindqvist, B., 1995. Mandibular function before and after orthodontic treatment. *European Journal of Orthodontics* 17, pp. 205–214.
- Pedroni, C.R., De Oliveira, A.S. & Guartini, M.I., 2003. Prevalence study of signs and symptoms of temporomandibular disorders in university students. *Journal of Oral Rehabilitation* 30, pp. 283–289.
- Piancino, M.G., Roberi, L., Frongia, G. et al., 2008. Computerized axiography in TMD patients before and after therapy with “function generating bites”. *Journal of Oral Rehabilitation* 35, pp. 88–94.
- Ramfjord, S.P., 1961. Dysfunctional temporomandibular joint and muscle pain. *Journal of Prosthetic Dentistry* 11, pp. 353–374.
- Rugh, J.D. & Solberg, W.K., 1985. Oral health status in the United States. Temporomandibular disorders. *Journal of Dental Education* 49, pp. 398–404.
- Sadowsky, C. & Polson, A.M., 1984. Temporomandibular disorders and functional occlusion after orthodontic treatment: results of two long-term studies. *American Journal of Orthodontics* 86, pp. 386–390.
- Schiffman, E. & Friction, J.R., 1988. Epidemiology of TMJ and craniofacial pain. In: Friction, J.R., Kroening, R.J. & Hathaway, K.M., eds. *TMJ and craniofacial pain: diagnosis and management*. St Louis: IEA Publications, pp. 1–10.
- Sonnesen, L. & Svensson, P. 2008. Temporomandibular disorders and psychological status in adult patients with a deep bite. *European Journal of Orthodontics* 30, pp. 621–629.
- Stohler, C.S. & Zarb, G.A. 1999. On the management of temporomandibular disorders: a plea for a low-tech, high prudence therapeutic approach. *Journal of Orofacial Pain* 13, pp. 255–261.
- Suvinen, T.I., Reade, P.C., Kempainen, P. et al., 2005. Review of aetiological concepts of temporomandibular pain disorders, towards a biopsychosocial model for integration of physical disorder factors with psychological and psychosocial illness impact factors. *European Journal of Pain* 9, pp. 613–633.
- Talaat, A.M., El-Dibany, M.M. & El-Garf, A., 1986. Physical therapy in the management of myofascial pain dysfunction syndrome. *Annals of Otological Rhinological Laryngology* 95, pp. 225–228.
- Tegeder, I. & Lötsch J., 2009. Current evidence for a modulation of low back pain by human genetic variants. *Journal of Cellular and Molecular Medicine* 13, pp. 1605–1619. DOI 10.1111/j.1582-4934.2009.00703.x.
- Truelove, E., Huggins, K.H., Mancl, L. et al., 2006. The efficacy of traditional, low-cost and non splint therapies for temporomandibular disorder. *Journal of the American Dental Association* 137, pp. 1099–1107.
- Turk, D.C., Zaki, H.S. & Rudy, T.E., 1993. Effect of intra-oral appliance and biofeedback/stress management alone and in combination in treating pain and depression in patients with temporomandibular disorders. *Journal of Prosthetic Dentistry* 70, pp. 158–164.
- U.S. Cochrane Center, 2002. *Training Manual for Handsearchers*. Available at: http://uscc.cochrane.org/Files/website_docs/Handsearcher%20Training%20Manual.pdf [Accessed November 20, 2010].

9

Self-Ligation

Padhraig S. Fleming, BDent Sc (Hons), MSc, MOrth RCS,
FDS (Orth) RCS

Senior Registrar, Department of Orthodontics, Royal London Dental Institute, London,
UK

Introduction

The quest to improve orthodontic force delivery and treatment efficiency is ongoing. Key developments over the past century have included the introduction of the edgewise appliance, hailed by its inventor as the “latest and the best” (Angle 1928); the discovery of enamel bonding techniques (Buonocore 1955); the subsequent application of bonding in orthodontics (Newman 1965); and the advent of the preadjusted edgewise appliance (Andrews 1976). Self-ligating brackets represent a further refinement.

Self-ligating brackets are ligatureless bracket systems having a mechanical device to close off the edgewise slot. Secure engagement may be produced by an in-built metal labial face or by a clip mechanism replacing the steel or elastomeric ligature. They have been marketed aggressively and used enthusiastically with over 42% of U.S. practitioners using at least one system in 2008 (Keim et al. 2008); this figure rose from just 8.7% in 2002 (Keim et al. 2002). In this chapter the merits of self-ligating brackets will be considered with particular emphasis on prospective clinical research.

History of Self-Ligating Appliances

The concept of self-ligating brackets was described initially in 1935 with the Russell Lock edgewise attachment (Stolzenberg 1935). The purported advantages of the earlier

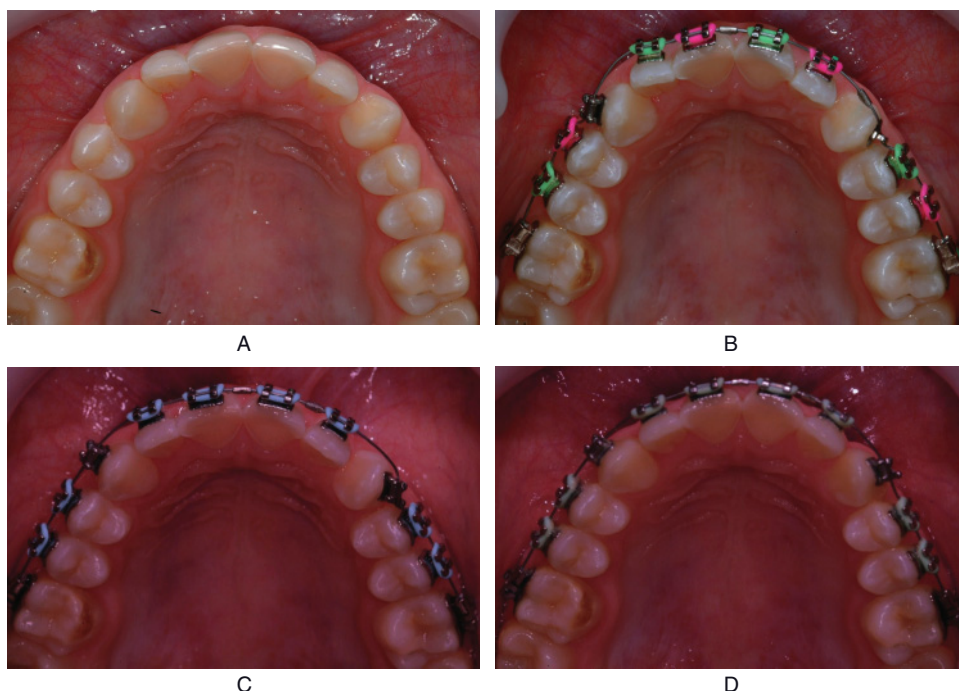


Figure 9.1 Sequential derotation of UL3 with selective use of InOvation R (GAC International, USA) self-ligating brackets. A traction hook was placed prior to placement of a bracket due to space limitation.

systems included enhanced versatility and a 50% improvement in operator efficiency; similar benefits are claimed today.

Properties of Conventional and Self-Ligating Preadjusted Edgewise Systems

Self-ligating appliances are claimed to allow more robust, secure ligation and to present reduced frictional resistance to tooth movement. These properties may translate into reduced overall treatment time (Harradine 2001; Eberting, Straja & Tuncay 2001; Harradine 2003), allowing more efficient alignment of irregular teeth (Figure 9.1) and more rapid space closure. Secure engagement has also prompted the use of active mechanics earlier in treatment (Figure 9.2). Additional advantages are claimed, including reduced patient discomfort, less root resorption, and enhanced plaque control (Shivapuja & Berger 1994).

These claims will be considered in the light of laboratory and clinical research findings. It is important to remember, however, that significant differences exist between the self-ligating systems, and therefore the findings from individual trials are not applicable to every self-ligating appliance. In particular, the mechanism of wire engagement varies among self-ligating brackets; wire ligation may be active or passive; brackets may be single or twin in morphology; and bracket dimensions and profiles differ.



A



B



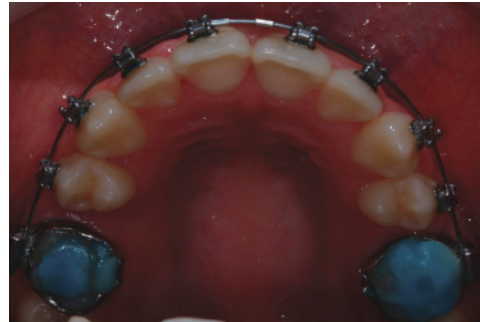
C



D



E



F

Figure 9.2 (A, B) Presenting malocclusion with severe maxillary arch crowding and palatal displacement of the maxillary lateral incisors. Both second premolars were extracted. (C–H) Light NiTi coil spring and elastomeric traction was placed on the initial aligning wire (C). Glass ionomer cement has been placed on the first molars to disengage the occlusion. At the second visit a 0.016-inch NiTi archwire was fully engaged (D); by this stage most of the upper arch spacing had been closed. (I–K) Case following removal of orthodontic appliances.



Figure 9.2 (Continued)

Laboratory Findings

Research on frictional resistance to orthodontic tooth movement is based on laboratory investigations using simulated oral environments. Studies have demonstrated that self-ligating brackets present less frictional resistance when sliding an archwire through aligned slots (Table 9.1). However, frictional resistance increases dramatically in self-ligating systems in regions of greater bracket displacement, corresponding to crowding in the clinical situation (Thorstenson & Kusy 2002).

Table 9.1 In vitro studies on the influence of bracket type and ligation mode on frictional resistance.

Study	Systems Tested	Highest Friction	Intermediate Friction	Lowest Friction
Shivapuja & Berger (1994)	7	Ceramic conventional*	SPEED	Edgelok
Voudouris (1997)	3	Sigma	Interactwin	Damon SL
Thomas Sherrif & Birnie (1998)	4	“A” Company Twin	Time	Damon
Kapur, Sinha & Nanda (1998)	2	MiniTwin	–	Damon
Pizzoni Ravnholt & Melsen (1998)	4	Conventional “A” Company	SPEED	Damon SL
Hain Dhopatkar & Rock (2003)	4	Victory with elastomerics	SPEED	Victory with loose steel ligatures
Khambay Millett & McHugh (2004)	4	Conventional appliance with elastomerics*	Conventional appliance with steel ligatures*	Damon 2
Griffiths, Sherriff & Ireland (2005)	4	Inspire with SuperSlick module	Inspire brackets with elastomeric	Damon 2
Tecco et al. (2005)	3	Victory	Damon 2	Time Plus
Henao & Kusy (2005)	4	Mini Diamond	Damon 2	In-Ovation

*Unspecified conventional fixed appliance.

Moreover, tooth movement has proven impossible to reproduce experimentally, making in vitro evidence potentially unreliable. The importance of friction in orthodontic appliances might also be overstated; vibration introduced by mastication significantly reduces friction when sliding a bracket along an archwire (Burrow 2009).

Retrospective Clinical Research

Initially, research on overall treatment time was studied retrospectively. Studies of this nature are invariably compromised due to the possibility of selection bias and uncontrolled factors including varying operator experience and preference, differing archwires and sequences, and inconsistent appointment intervals.

Harradine (2001) retrospectively compared the overall treatment duration of 30 cases treated with Damon SL brackets to 30 matched cases treated by the same operator with conventional brackets. The Damon SL cases required an average of 4 fewer months (19.4 versus 23.5 months) and 4 fewer visits (12.7 versus 16.5) in order to be treated to an

equivalent standard based on Peer Assessment Rating scores. The author conceded that the selection of cases for inclusion may have reflected a “tendency to include only the more successful and pleasing.” A further clinical study in three practices found an average reduction in treatment time of 6 months (31 versus 25 months) and 7 visits (from 28 to 21) for Damon SL™ cases compared with conventional ligation (Eberting, Straja & Tuncay 2001). However, Hamilton, and colleagues (2008) in a larger sample of 762 patients contradicted these findings, failing to detect a difference between appliance types. The average treatment duration in this study was just 15.7 months.

Miles, Weyant & Rustveld (2006) commenting on early retrospective studies, proposed that the reduction in treatment times described may merely reflect a transition to more efficient treatment systems rather than being related purely to use of the self-ligating appliance. It seems likely that, with the advent of more efficient treatment approaches, the use of self-ligating brackets is likely to be less influential. In addition it is interesting to note the considerable discrepancy in the length of treatment and the number of visits required between the three retrospective studies.

Prospective Research

Treatment Outcomes and Duration

Over the past 4 years, prospective clinical studies investigating the properties of self-ligating brackets have emerged. These studies have considered surrogate measures of treatment efficiency, including the efficiency of initial orthodontic alignment and the rate of orthodontic space closure, overall treatment duration, arch dimensional changes, bond failure rate, subjective pain experience, degree of root resorption, and periodontal effects related to both systems.

Efficiency and Ease of Use

Self-ligation seems to result in a modest but consistent reduction in chairside time over conventional appliances (Table 9.2). Authors have suggested this saving could be used to schedule more patients, increase efficiency, improve patient relations, or allow oral hygiene reinforcement (Maijer & Smith 1990).

Efficiency of Arch Alignment

A number of prospective studies have investigated the efficiency of initial orthodontic alignment over a period of up to 20 weeks. The results from these trials have been consistent, indicating that self-ligating brackets may offer no advantage with respect to treatment efficiency (Table 9.3).

Miles (2005) compared the alignment efficiency of SmartClip brackets and conventional twin brackets in a prospective analysis of 48 patients. The SmartClip bracket was no more effective at reducing irregularity during the initial stage of treatment than a conventional twin bracket ligated with elastomeric modules or stainless steel ligatures. Slightly more irregularity remained after initial alignment in the group treated with SmartClip than in a group treated with Victory; this was attributed to the rotational play of 6.8 degrees

Table 9.2 Reported time savings with self-ligating over conventional systems.

Study	Self-ligating System(s)	Conventional Mode of Ligation	Time Savings
Maijer & Smith (1990)	SPEED	Elastomerics	7 min.
Shivapuja & Berger (1994)	Activa, Edgelok, SPEED	Wire ligatures	12 min.
		Elastomerics	1 min.
Voudouris (1997)	Interactwin	Elastomerics	2.5 min.
	SPEED	Elastomerics	2–3 min.
Berger & Byloff (2001)			
Harradine (2001)	Damon SL	Elastomerics	25 sec.
Turnbull & Birnie (2007)	Damon 2	Elastomerics	1.5 min.
Paduano et al. (2008)*	Time 2	Elastomerics	1.7 min.
	SmartClip		
	In-Ovation	Stainless steel ligatures	2.68 min

*Figures relate to the maxillary arch.

allowed by the passive self-ligating system using a 0.014-inch aligning NiTi wire. This study was limited by a small sample size, two-dimensional measurement, inclusion of both extraction and nonextraction cases, and confinement of measurement to the labial segment only.

These findings were mirrored by Scott et al. (2008a) in a randomized controlled trial of Damon 3 and a conventional appliance in subjects treated with mandibular first premolar extraction. The measurement technique deployed was similar to that reported by Miles (2005).

In a further clinical investigation of 58 patients, Miles Weyant & Rustveld (2006) compared efficiency of alignment and patient comfort related to Damon 2 and a conventional twin bracket in nonextraction cases, using a split-mouth study design. At 10-week and 20-week intervals, the twin bracket had achieved an irregularity index of 0.2 mm lower than Damon 2 brackets. The initial aligning wire used in that trial was also 0.014-inch NiTi with the potential for greater rotational play.

Pandis, Polychronopoulou & Eliades (2007) in a controlled clinical trial involving Damon II and Microarch appliances reported no significant difference overall in the time taken to align the mandibular arch. A further randomized controlled trial (Fleming et al. 2009a) has reported little difference in alignment efficiency with an initial aligning wire (0.016-inch NiTi) with SmartClip and Victory systems in subjects treated without extraction. This study of 65 patients involved detailed 3-D measurements and included 11 mandibular contact points.

These findings involving 287 participants overall indicate that any time saving arising from use of self-ligating brackets does not occur in the initial alignment phase of treatment. Alleviation of dental irregularity is impossible to measure perfectly; most trials have failed to control for individual metabolic variation; and the results may have been unintentionally

Table 9.3 Comparative studies of the rate of initial orthodontic alignment with self-ligating brackets and conventional brackets.

Study	Methods	Subjects	Interventions	Outcomes
Miles (2005)	CCT, Observed at 10 and 20 weeks	48 patients. Mean age 17.1 years, 26 male, 32 female	Group 1: 24 patients with SmartClip Group 2: 24 patients with Victory	Rate of initial alignment lower 3-3
Miles, Weyant & Rustveld (2006)	CCT, split-mouth design Observed at 10 and 20 weeks	58 consecutive patients. Mean age 16.3 years, 18 male, 40 female	Lower appliance with Damon 2 or Victory brackets in alternate quadrants	Rate of initial alignment lower 3-3
Pandis, Polychronopoulou & Eliades (2007)	CCT, Observed until alignment achieved	54 patients. Mean age 13.7 (1.38) years, 11 male, 43 female	Group 1: 27 patients with Damon 2 Group 2: 27 patients with Microarch, GAC	Time taken (days) to align lower 3-3
Scott et al. (2008a)	RCT, Observed at 8 weeks and following mandibular alignment	62 patients recruited. Mean age 16.27 (4.47) years, 32 male, 30 female	Group 1: 33 patients with Damon 3 Group 2: 29 patients with Synthesis	Rate of initial alignment lower 3-3 Time taken (days) to align lower arch in $0.019 \times 0.025''$ SSW
Fleming et al. (2009a)	RCT, Observed at 8 weeks	65 patients. Mean age 16.28 (2.68) years, 22 male, 43 female	Group 1: 32 patients with SmartClip Group 2: 33 patients with Victory	Rate of initial alignment lower 6-6

biased by inaccurate bracket placement. Nevertheless, unless time savings arise later in treatment, on the basis of these prospective studies it seems unlikely that self-ligating systems counterbalance their cost by resulting in more efficient treatment or better treatment outcomes.

Rate of Space Closure

Miles (2007) considered the rate of orthodontic space closure in a split-mouth design negating the influence of metabolic variation. No statistical difference was found between the appliance types. This study had an inadequate sample size with 4 of 18 subjects failing to complete the study. Posted archwires were used on both sides; this design meant that rate of space closure on each side may not have been completely independent of the opposing side.

Overall Treatment Duration

To date just one prospective clinical study (Fleming, DiBiase & Lee 2010) has considered the influence of bracket type on overall treatment duration. This study was based in a hospital setting and comprised 54 patients; all subjects were treated without mandibular arch extractions. Cases were treated to a similar standard as adjudged using the Peer Assessment Rating. No statistical difference in treatment duration was noted between the appliance systems investigated.

On the basis of this research, it is doubtful whether a fixed appliance system may have a significant bearing on the duration of orthodontic treatment or on the number of visits required. Moreover, duration is likely to be governed by the skill, experience, and objectives of the treating clinician in addition to the dictates of the presenting malocclusion. Nevertheless, additional prospective research involving larger samples with similar pre-treatment occlusal traits are needed to investigate this further.

Arch Dimensional Changes and Torque Expression

Pandis, Strigou & Eliades (2006) in a prospective cohort study reported similar torque expression with both Damon II and MicroArch appliances relative to the sella-nasion and nasion-A point lines. In relation to the mandibular arch, Fleming et al. (2009b), Pandis, Polychronopoulou & Eliades (2007), and Pandis et al (2010a) reported identical incisor proclination and intercanine expansion with both appliance systems during arch alignment.

Statistically greater intermolar expansion associated with self-ligating appliances arose with SmartClip (Fleming et al. 2009b) and Damon II (Pandis et al. 2010a) appliances. This finding occurred despite the use of archwires of uniform dimensions in both groups and the profile of the bracket types being similar. Additionally, potential confounding factors including pre-treatment intermolar dimension and the degree of crowding resolved during treatment were accounted for in the statistical analyses (Fleming et al. 2009b). This outcome indicates that the mechanism of arch alignment produced by self-ligating systems may be slightly different from that developing with conventional appliances.

Further research investigating potential differences in the pattern of arch alignment related to bracket type would be welcome. Furthermore, it remains to be seen whether use of expanded archwire forms with particular appliances promotes transverse increases.

Influence of Self-Ligating Brackets on Deleterious Effects of Treatment

It has been suggested that reduced frictional resistance and the application of lighter forces with self-ligating brackets would translate into less deleterious sequelae, for example subjective discomfort and root resorption.

Subjective Pain Experience

Four prospective studies, including three randomized clinical trials, have been conducted to investigate subjective pain experience following initial placement of self-ligating and conventional appliances (Miles, Weyant & Rustveld 2006; Scott et al. 2008b; Fleming et al. 2009c; Pringle et al. 2009). Of these, one split-mouth study has considered pain reports after both the first and second visits, with slightly less pain experience initially reported with the self-ligating appliance system (Miles, Weyant & Rustveld 2006).

Data in the three randomized trials were reported as pain scores from 0 to 100 on a 100-mm visual analog scale (Scott et al. 2008b; Fleming et al. 2009c; Pringle et al. 2009). In one trial subjects recorded pain scores at 15 time intervals; two trials used four time points: 4 hours, 24 hours, 3 days, and 7 days after appliance placement. Reported pain peaked within 24 hours (Scott et al. 2008b; Fleming et al. 2009c; Pringle et al. 2009) before subsiding to near baseline levels 7 days after appliance placement. The findings from these studies conflicted slightly with one study reporting a tendency to less pain experience with Damon 3 self-ligating brackets, although this finding did not reach statistical significance (Pringle et al. 2009). The other two studies found no difference between the systems. It is unclear why this discrepancy arose; all studies were of high methodological quality and were carried out in similar hospital settings, with analogous age and gender distributions (Scott et al. 2008b; Fleming et al. 2009c; Pringle et al. 2009). The failure to highlight a significant bracket-related effect is compatible with previous research indicating a lack of association between archwire material (Jones & Chan 1992) and dimension (Erdoğan & Dinçer 2004) and pain experience. Clearly, pain is influenced by a variety of factors, with individual susceptibility being critical.

Fleming et al. (2009c) assessed pain experienced during chairside manipulation of the appliance at a specific stage during treatment. Miles, Weyant and Rustveld (2006) considered this property during earlier stages of treatment. Both studies reported greater pain experience with the self-ligating appliances; however, the mechanisms of archwire engagement and disengagement are very different with different appliance systems. Therefore, this may not be a universal finding.

Apical Root Resorption

Pandis et al. (2008a), using panoramic radiographs, reported no mean difference in the amount of apical root resorption of the maxillary incisors arising during treatment with Microarch and Damon 2 systems. Similar results were obtained by Scott et al. (2008a) who assessed changes in root lengths of mandibular incisors on periapical radiographs following arch alignment. The mean amount of resorption was slightly greater with the Damon 3 appliance (2.26 vs. 1.21 mm), although the difference failed to reach statistical significance.

Plaque Retention and Periodontal Health

The short-term impact of bracket design on plaque retention has been assessed in two studies (Pellegrini et al. 2009; Pandis et al. 2010b). Pellegrini et al. in a split-mouth study investigated plaque retention using ATP-driven bioluminescence to assess bacterial load. Mean streptococcal and total bacterial levels harvested from tooth surfaces 1 and 5 weeks after appliance placement were lower with the self-ligating bracket ($P < 0.05$). A further prospective trial, however, failed to show an association between bracket type and bacterial load (Pandis et al. 2010b). This finding may reflect the different measurement technique deployed involving estimation of salivary levels of *Streptococcus mutans* (Pandis et al. 2010b).

In addition, Pandis et al. (2008b) found no association between bracket type and periodontal health following removal of orthodontic appliances. It appears that, while bracket type may influence bacterial aggregation with appliances in situ, this effect may be without long-term consequence due to the reparative capacity of the periodontal tissues.

Conclusions

While self-ligating brackets represent state-of-the-art bracket technology and command a burgeoning market share, there remains little reliable evidence to support their superiority over conventional bracket systems. In particular, prospective research has failed to demonstrate time savings in relation to overall treatment duration or fewer deleterious effects of fixed appliance therapy. There is, however, a definite but modest reduction in time and assistance required to adjust self-ligating appliances.

While a lack of supporting evidence does not invalidate the appliances, further investigations are indicated to provide an evidence-based foundation to underpin our clinical decisions. Further research should be reported in accordance with the CONSORT guidelines (Altman et al. 2001) and should have adequate sample size to avoid false-negative outcomes.

References

- Altman, D.G., Schulz, K.F., Moher, D. et al., 2001. The revised CONSORT statement for reporting randomized trials: explanation and elaboration. *Annals of Internal Medicine* 134, pp. 663–694.
- Andrews, L.F., 1976. The straight-wire appliance, origin, controversy, commentary. *Journal of Clinical Orthodontics* 10, pp. 99–114.
- Angle, E.H., 1928. The latest and best in orthodontic mechanism. *Dental Cosmos* 70, pp. 1143–1158.
- Berger, J. & Byloff, F.K., 2001. The clinical efficiency of self-ligated brackets. *Journal of Clinical Orthodontics* 35, pp. 304–308.
- Buonocore, M.G., 1955. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. *Journal of Dental Research* 34, pp. 849–853.
- Burrow, S.J., 2009. Friction and resistance to sliding in orthodontics: a critical review. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, pp. 442–447.
- Eberting, J.J., Straja, S.R. & Tuncay, O.C., 2001. Treatment time, outcome, and patient satisfaction comparisons of Damon and conventional brackets. *Clinical Orthodontic Research* 4, pp. 228–234.

- Erdoğan, A.M. & Dinçer, B., 2004. Perception of pain during orthodontic treatment with fixed appliances. *European Journal of Orthodontics* 26, pp. 79–85.
- Fleming, P.S., DiBiase, A.T. & Lee, R.T., 2010. Randomized clinical trial of orthodontic treatment efficiency with self-ligating and conventional fixed orthodontic appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* 6, pp. 738–742.
- Fleming, P.S., DiBiase, A.T., Sarri, G. et al., 2009a. Efficiency of mandibular arch alignment with 2 preadjusted edgewise appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, pp. 597–602.
- Fleming, P.S., DiBiase, A.T., Sarri, G. et al., 2009b. Comparison of mandibular arch changes during alignment and leveling with 2 preadjusted edgewise appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* 136, pp. 340–347.
- Fleming, P.S., DiBiase, A.T., Sarri, G. et al., 2009c. Pain experience during initial alignment with a self-ligating and a conventional fixed orthodontic appliance system. A randomized controlled clinical trial. *The Angle Orthodontist* 79, pp. 46–50.
- Griffiths, H.S., Sherriff, M. & Ireland, A.J., 2005. Resistance to sliding with 3 types of elastomeric modules. *American Journal of Orthodontics and Dentofacial Orthopedics* 127, pp. 670–675.
- Hain, M., Dhoptkar, A. & Rock, P., 2003. The effect of ligation method on friction in sliding mechanics. *American Journal of Orthodontics and Dentofacial Orthopedics* 123, pp. 416–422.
- Hamilton, R., Goonewardene, M.S. & Murray, K., 2008. Comparison of active self-ligating brackets and conventional pre-adjusted brackets. *Australian Orthodontic Journal* 24, pp. 102–109.
- Harradine, N.W., 2001. Self-ligating brackets and treatment efficiency. *Clinical Orthodontic Research* 4, 220–227.
- Harradine, N.W., 2003. Self-ligating brackets: where are we now? *Journal of Orthodontics* 30, pp. 262–273.
- Henao, S.P. & Kusy, R.P., 2005. Frictional evaluations of dental typodont models using four self-ligating designs and a conventional design. *The Angle Orthodontist* 75, pp. 75–85.
- Jones, M.L. & Chan, C., 1992. Pain in the early stages of orthodontic treatment. *Journal of Clinical Orthodontics* 26, pp. 311–313.
- Kapur, R., Sinha, P.K. & Nanda, R.S., 1998. Frictional resistance of the Damon SL bracket. *Journal of Clinical Orthodontics* 32, pp. 485–489.
- Keim, R.G., Gottlieb, E.L., Nelson, A.H. et al., 2002. JCO study of orthodontic diagnosis and treatment procedures. Part 1. Results and trends. *Journal of Clinical Orthodontics* 36, pp. 553–568.
- Keim, R.G., Gottlieb, E.L., Nelson, A.H. et al., 2008. JCO study of orthodontic diagnosis and treatment procedures. Part 1. Results and trends. *Journal of Clinical Orthodontics* 42, pp. 625–640.
- Khambay, B., Millett, D. & McHugh, S., 2004. Evaluation of methods of archwire ligation on frictional resistance. *European Journal of Orthodontics* 26, pp. 327–332.
- Maijer, R. & Smith, D.C., 1990. Time saving with self-ligating brackets. *Journal of Clinical Orthodontics* 24, pp. 29–31.
- Miles, P.G., 2005. SmartClip versus conventional twin brackets for initial alignment: is there a difference? *Australian Orthodontic Journal* 21, pp. 123–127.
- Miles, P.G., 2007. Self-ligating vs conventional twin brackets during en-masse space closure with sliding mechanics. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 223–225.
- Miles, P.G., Weyant, R.J. & Rustveld, L., 2006. A clinical trial of Damon 2 vs conventional twin brackets during initial alignment. *The Angle Orthodontist* 76, pp. 480–485.
- Newman, G.V., 1965. Epoxy adhesives for orthodontic attachments: progress report. *American Journal of Orthodontics* 51, pp. 901–912.
- Paduano, S., Cioffi, I., Iodice, G. et al., 2008. Time efficiency of self-ligating vs conventional brackets in orthodontics; effect of appliance and ligating systems. *Progress in Orthodontics* 9, pp. 74–80.

- Pandis, N., Nasika, M., Polychronopoulou, A. et al., 2008a. External apical root resorption in patients treated with conventional and self-ligating brackets. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 646–651.
- Pandis, N., Polychronopoulou, A. & Eliades, T., 2007. Self-ligating vs conventional brackets in the treatment of mandibular crowding: a prospective clinical trial of treatment duration and dental effects. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 208–215.
- Pandis, N., Polychronopoulou, A., Makou, M. et al., 2010a. Mandibular dental arch changes associated with treatment of crowding using self-ligating and conventional brackets. *European Journal of Orthodontics* 3, pp. 248–253.
- Pandis, N., Papaioannou, W., Kontou, E. et al., 2010b. Salivary *Streptococcus mutans* levels in patients with conventional and self-ligating brackets. *European Journal of Orthodontics* 1, pp. 9–99.
- Pandis, N., Strigou, S. & Eliades, T., 2006. Maxillary incisor torque with conventional and self-ligating brackets: a prospective clinical trial. *Orthodontic and Craniofacial Research* 9, pp. 193–198.
- Pandis, N., Vlachopoulos, K., Polychronopoulou, A. et al., 2008b. Periodontal condition of the mandibular anterior dentition in patients with conventional and self-ligating brackets. *Orthodontic and Craniofacial Research* 11, pp. 211–215.
- Pellegrini, P., Sauerwein, R., Finlayson, T. et al., 2009. Plaque retention by self-ligating vs elastomeric orthodontic brackets: quantitative comparison of oral bacteria and detection with adenosine triphosphate-driven bioluminescence. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, pp. 426.e1–9.
- Pizzoni, L., Ravnholt, G. & Melsen, B., 1998. Frictional forces related to self-ligating brackets. *European Journal of Orthodontics* 20, pp. 283–291.
- Pringle, A.M., Petrie, A., Cunningham, S.J. et al., 2009. Prospective randomized clinical trial to compare pain levels associated with 2 orthodontic fixed bracket systems. *American Journal of Orthodontics and Dentofacial Orthopedics* 136, pp. 160–167.
- Scott, P., DiBiase, A.T., Sherriff, M. et al., 2008a. Alignment efficiency of Damon3 self-ligating and conventional orthodontic bracket systems: a randomized clinical trial. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 470.e1–8.
- Scott, P., Sherriff, M., DiBiase, A.T. et al., 2008b. Perception of discomfort during initial orthodontic tooth alignment using a self-ligating or conventional bracket system: a randomized clinical trial. *European Journal of Orthodontics* 30, pp. 227–232.
- Shivapuja, P.K. & Berger, J., 1994. A comparative study of conventional ligation and self-ligation bracket systems. *American Journal of Orthodontics and Dentofacial Orthopedics* 106, pp. 472–480.
- Stolzenberg, J., 1935. The Russell attachment and its improved advantages. *International Journal of Orthodontia and Dentistry for Children* 21, pp. 837–840.
- Tecco, S., Festa, F., Caputi, S. et al., 2005. Friction of conventional and self-ligating brackets using a 10 bracket model. *The Angle Orthodontist* 75, pp. 1041–1045.
- Thomas, S., Sherriff, M. & Birnie, D., 1998. A comparative in vitro study of the frictional characteristics of two types of self-ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures. *European Journal of Orthodontics* 20, pp. 589–596.
- Thorstenson, G.A. & Kusy, R.P., 2002. Comparison of resistance to sliding between different self-ligating brackets with second-order angulation in the dry and saliva states. *American Journal of Orthodontics and Dentofacial Orthopedics* 121, pp. 472–482.
- Turnbull, N.R. & Birnie, D.J., 2007. Treatment efficiency of conventional vs self-ligating brackets: effects of archwire size and material. *American Journal of Orthodontics and Dentofacial Orthopedics* 131, pp. 395–399.
- Voudouris, J.C., 1997. Interactive edgewise mechanisms: form and function comparison with conventional edgewise brackets. *American Journal of Orthodontics and Dentofacial Orthopedics* 111, pp. 119–140.

Prevention of Demineralization During Orthodontic Treatment with Fluoride-Containing Materials or Casein Phosphopeptide-Amorphous Calcium Phosphate

Philip E. Benson, PhD, FDS (Orth) RCS, MOrth RCS, MSc, PhD, FHEA

Reader/Honorary Consultant in Orthodontics, University of Sheffield School of Clinical Dentistry, Sheffield, UK

Background

It is well recognized that orthodontic appliances can lead to the accumulation of plaque and that plaque is a major etiological factor in the process that leads to demineralization of dental enamel. Orthodontic appliances that are not properly cleaned can therefore increase the incidence of enamel demineralization.

Approaches to reducing the incidence of demineralization during orthodontic treatment have either involved decreasing the amount of plaque (by insisting that the patient maintains good oral hygiene or less commonly by chemical methods) or by tackling the susceptibility of enamel to demineralization. The aim of this chapter is to outline the evidence regarding the effectiveness of the latter approach.

Evidence-Based Orthodontics, First Edition. Edited by Greg J. Huang, Stephen Richmond and Katherine W.L. Vig.

© 2011 Blackwell Publishing Ltd. Published 2011 by Blackwell Publishing Ltd.

Reducing the Susceptibility of Enamel to Demineralization

It has been known for many years that fluoride reduces the incidence of dental caries (Dean et al. 1950), but it was thought that this was because ingested fluoride ions are incorporated into the hydroxyapatite crystal, making it less soluble when subjected to the acids produced by plaque bacteria. It is now known that the main mechanism by which fluoride works is not systemic, but local, by maintaining the plaque fluoride supersaturated with respect to fluorapatite, hence tipping the balance of the caries process against demineralization and in favor of remineralization (Hellwig & Lennon 2004). This means that topically applied fluoride is a potentially important method of reducing the incidence of demineralization in orthodontic patients, who are well past the age when fluoride can be delivered systemically. In order to be effective, fluoride should be available frequently but does not need to be in a high concentration. Levels as low as 0.01 ppm F promote remineralization (ten Cate 1997).

More recently it has been suggested that the compound casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) may also reduce the incidence of demineralization. The theoretical basis of this arose from the observation that dairy products are anticariogenic. They work in a way similar to fluoride by maintaining the saturation of calcium and phosphate in plaque fluid, thereby discouraging the dissolution of these elements and also promoting remineralization if they are lost (Reynolds 1997).

Methods of Applying Fluoride/CPP-ACP

There are two main methods of exposing the patient to either fluoride or CPP-ACP.

- **Topical:** In topical form the active ingredient are supplied in forms such as a toothpaste, mouth rinse, gel, varnish, mousse, lozenge, cream or by adding it to milk or chewing gum. Gels and varnishes are usually applied by a professional, particularly if they contain a high concentration of fluoride, whereas the other means of topical application can be self-administered. This has the advantage that the clinician is not relying on the patient to act on the instructions given, but has the disadvantage that the topical form cannot be given frequently, which is preferred in order to promote remineralization.
- **Materials Containing the Active Ingredient** Fluoride or CPP-ACP can be added to a material used as part of the appliance, either as a bonding or banding material, or an auxiliary such as a glass bead or elastic.

Before examining the evidence that either fluoride or CPP-ACP are effective in reducing the incidence of demineralization during orthodontic treatment, some of the shortcomings of research in this area should be considered.

Limitations of Previous Research

Laboratory Studies

Much of the work examining the effectiveness of fluoride or CPP-ACP in preventing orthodontic demineralization has been carried out in the laboratory. Researchers have attached orthodontic brackets to extracted teeth, subjected the samples to various demin-

eralizing and remineralizing solutions or gels, and measured the amount or depth of mineral loss. The main advantage of undertaking a laboratory study is that this reduces the range and number of variables that might impact the caries process. This will lessen the variability of the data and therefore decrease the number of samples required in order to detect a significant difference. Destructive techniques of determining mineral loss and lesion depth can be used to measure the outcomes accurately, and reproducibly and results are produced quickly and relatively simply.

Unfortunately the strength of laboratory studies, namely that conditions can be controlled very closely, also means that the results are of limited value to the clinician. Laboratory studies are not able to reproduce the many variables that are present in individual patients, such as salivary flow and constituents, dietary (including fluoride) intake, and temperature changes, let alone the difference in susceptibility of each person to caries. Laboratory work is helpful when investigating how materials work and is essential to determine the biocompatibility, but it is of very limited use in assessing clinical effectiveness, which requires well-designed clinical trials.

Clinical Trials—Random or Alternate Allocation?

Some investigators have designed their clinical trials so that experimental and control material is allocated on an alternate basis to patients, arches, or quadrants. Although it could be considered that consecutive patients attending an orthodontist will be fairly randomly distributed with regard to oral hygiene, compliance with instructions, susceptibility to caries, etc., it is important that researchers design their clinical trials so that any possibility of selection or allocation bias is as small as possible. Hence there is a need for detailed inclusion and exclusion criteria for the selection of participants and proper randomization and concealment methods for the allocation to groups.

Short Term or Long Term?

Some clinical studies have only investigated how the material performs in the first few weeks after the orthodontic appliance has been placed (Gorton & Featherstone 2003, Pascotto et al. 2004). This is because they are examining teeth that are due to be extracted as part of the orthodontic treatment plan. Unfortunately, this gives the clinician limited information about how the material will perform over the whole course of orthodontic treatment, which may take many months or years. In the case of materials containing substances that leach out, such as fluoride, it is possible that this will overestimate their effectiveness. We know that there is rapid loss of fluoride in the first few hours and days after it is placed, which is followed by slower and lower levels of loss thereafter. Longer-term studies will also provide information about how the therapeutic agent is lost from the materials, and, in the case of fluoride, if the material also absorbs dietary fluoride into the material (a phenomenon known as “recharge”) and how this affects the demineralization process.

Parallel, Split-Mouth, or Crossover Design?

In addition to the length of the investigation, the results may also be influenced by the design of the study. It is tempting for researchers to undertake a study using a split-mouth or a crossover design, whereby both control and experimental materials are tested in the

same participant involved in the trial. In a split-mouth study, the control material is used to bond a bracket to a tooth on one side of the mouth (or arch), and the experimental material is used to bond a bracket to a tooth on the other side of the mouth (or arch). In a crossover study a topically applied control product may be used for a period of time followed by the topically applied experimental product after a suitable “wash-out” period between them to ensure there are no carryover effects. The sides of the mouth or order in which control and experimental products are supplied should be randomly allocated. The advantage of these designs is that the products are tested within the same mouth, theoretically reducing interparticipant variables such as diet, salivary constituents and flow, and individual susceptibility to caries. The problem with the crossover design is that the product is tested for only a limited part of the time that it takes to carry out orthodontic treatment. The disadvantage of the split-mouth study is the possibility that some of the therapeutic element will cross from the experimental quadrant or arch to the opposite, control quadrant or arch, reducing the difference in the incidence of demineralization between the control and experimental materials. The appropriate design for a clinical trial to determine the effectiveness of products in reducing demineralization during orthodontic treatment is therefore that of parallel groups.

Relevant Outcomes

Researchers have used various ways of studying demineralization and more recently remineralization of dental tissues. Early techniques, such as polarized light microscopy and microhardness testing, have been largely superseded and more up-to-date methods should be used, such as computerized microradiography, tomography, and quantitative light-induced fluorescence (QLF). These techniques have been validated to show small changes in mineral loss and lesion depth.

These methods are appropriate for the cariologist investigating the caries process but are less suited to study the effectiveness of products in preventing demineralization during orthodontic treatment. I suggest that the patient and clinician are more interested in the aesthetic problems associated with demineralization. They want to know firstly if there will be fewer unsightly white spots and, secondly, should white spots occur, will they be smaller or less white (demineralized) and therefore less obvious? The researcher does not necessarily require sophisticated (and expensive) research tools to assess these outcomes. Both the number of new white spots (incidence) and the size and whiteness (severity) can be determined from clinical photographs.

Masking of Patients and Clinicians

Ideally, both patient and clinician involved in a clinical trial should be unaware of whether the patient has been allocated to receive the experimental or the control material (double-blind). This technique is used to reduce the potential for participants to influence the results by changing behavior, for example by taking extra care with oral hygiene practices for their favored product. In the case of a topical application, this is relatively straightforward, as two products can be prepared by the manufacturer that are identical in every way, except that one contains the active ingredient (experimental) and one does not (control). It is harder to do with bonding agents that may have different methods of preparing the enamel and curing the material.

Masking of the person treating the patient might not be possible, but it is essential in all studies that the person assessing the demineralized lesions does not know in which group the patient has been allocated. Clinical photographs or QLF images provide a permanent record that allows suitable masking of judges. They also enable the assessment of repeatability within the same judge and reproducibility between judges, which is another essential component of a clinical study. If the variability of the judges in assessing the presence or absence of a demineralized lesion on duplicate images of the same tooth is greater than the difference in their assessment between the experimental and control material, then the validity of the results must be questioned.

Incidence versus Prevalence

The appropriate primary outcome to determine the effectiveness of preventive products is the number of new demineralized lesions appearing during treatment (incidence). Assessment of teeth only at the end of treatment (prevalence) will obviously not exclude those lesions that were present before the appliance was fitted. This requires the researcher to record the appearance of the teeth both just before the appliance is fitted and very soon after it has been removed. Any delay between taking the photographs and fitting the appliance or between removing the appliance and taking the photographs risks the possibility that new demineralized lesions will appear or that any lesions present will remineralize, and this could alter the results of the trial.

In addition, there are many causes of white lesions on enamel other than from demineralization. Although it would be ideal to confirm that a white lesion is caused by demineralization, perhaps by using a fluorescent technique, an experienced clinician can reliably identify a demineralized lesion occurring during orthodontic treatment. Even an inexperienced person, when shown the pretreatment and posttreatment images together, should be able to determine if there has been any change.

Inappropriate Statistical Analyses

Many studies carried out in this area have used the incidence or prevalence of demineralization on individual teeth as the unit for statistical analysis. An assumption made by most statistical tests is that each unit entered into the analysis is independent of the other units. Unfortunately, one tooth in an individual's mouth is subjected to similar, if not the same, conditions of saliva, diet, and oral hygiene practices as the tooth next to it. Therefore, the assumption that each tooth within the mouth of a participant in a clinical trial is an independent unit is incorrect. The proper unit for the purpose of statistical analysis of the data generated during a clinical trial in this area is the patient, which further supports the need for a parallel groups design. For further details about an appropriate presentation of the data and statistical analysis please see Box 10.1.

Lack of Sufficient Power

The recognition that the patient, rather than the tooth, is the appropriate unit for statistical analysis for clinical trials in the area of demineralization will increase considerably the number of participants that need to be recruited to the trial in order to detect a significant

Box 10.1 The Calculation of Relative Risk for the Dichotomous Outcome (presence or absence of new demineralized lesions) in Parallel and Split-Mouth Studies

To assess whether the fluoride-containing experimental material or the non-fluoride-containing control material is more likely to have a new demineralized lesion the relative risk can be calculated.

A 2×2 contingency table is constructed.

		Control Material	Experimental Material	Total
New Demineralized Lesion	Yes	a	b	$a + b$
	No	c	d	$c + d$
	Total	$a + c$	$b + d$	n

Where:

- a = the number of patients with control material who had at least one new demineralized lesion;
- b = the number of patients with experimental material who had at least one new demineralized lesion;
- c = the number of patients with control material who had no new demineralized lesions; and
- d = the number of patients with experimental material who had no new demineralized lesions.

$$a + b + c + d = \text{the number of patients in the trial.}$$

$$\text{Risk Ratio} = \frac{a/(a + c)}{b/(b + c)}$$

Under the null hypothesis, the expected value of RR is 1.

Split-mouth studies will require a different format. The data should be arranged per quadrants (not individual teeth) as outlined in the table below.

		Fluoride Intervention	
		New Demineralized Lesion	
Control	New Demineralized Lesion	Yes	No
	Yes	a	b
	No	c	d
		$a + b + c + d = n$	

Where:

- a = the number of patients who had at least one new demineralized lesion present in both the experimental and the control arches (or quadrants);
- b = the number of patients who had at least one new demineralized lesion present in the control arch, but not in the experimental arch;
- c = the number of patients who had at least one new demineralized lesion present in the experimental arch, but not in the control arch; and
- d = the number of patients who had no demineralized lesions present in either the experimental or the control arches.

If there are two experimental and two control quadrants per individual, then ideally the two experiment quadrants and the two control quadrants should be combined. If this is the case then:

$$a + b + c + d = \text{the number of patients in the trial.}$$

If the data for combined quadrants is not available, then it should be possible to use the data for upper and lower quadrants, in which case:

$$a + b + c + d = \text{twice the number of patients in the trial.}$$

Ideally the data should be for the number of new lesions, which were assessed immediately after debond.

First published in *Seminars in Orthodontics* (2010; 16:293–301), reproduced with permission.

difference between two products. Another problem when attempting to establish a suitable sample size is an accurate determination of the incidence of the condition. It has been quoted as anything between 2% and 96%, depending upon the methods used, particularly whether individual teeth or patients are assessed (Mitchell 1992). If the incidence of a particular condition is low, then a large sample size is required in order to detect a significant difference. This is because a significant proportion of the participants in the trial will not be affected by the condition, and it makes no difference if they receive the control or experimental product. If the incidence is high, then a larger proportion of the sample recruited will be potentially affected by the condition; therefore, the researcher has a higher chance of determining if one product is more effective at reducing the incidence of the condition compared with a second product.

A second judgment the researcher needs to make when deciding on the number of participants required is the size of the difference to be detected. It could be argued that if a product prevents demineralized lesions in one patient, then it would be worth recommending, but this does not take into account any potential costs to the patient in terms of time, inconvenience, and money, particularly if they were in the proportion who were very unlikely to suffer the condition anyway. It would also require a very large sample size in order to detect such a small difference; therefore, a more realistic target should be set.

Reporting of Trials

One final frustrating aspect for those who try to summarize the findings of clinical trials is the incomplete or inaccurate reporting by authors of the details of their study. On many occasions when contacting authors requesting further details or clarification about certain aspects of their trial they are unable to provide the information required. This is bad enough if the enquiry is out of personal interest, but if it means the results of the study has to be excluded from a systematic review, then this is clearly detrimental to both patients and clinicians who would find the information useful to inform their clinical practice.

To address the issue of poor reporting in randomized controlled trials a meeting of experts in the field of clinical trials issued the Consolidated Standards of Reporting Trials (CONSORT) Statement in 1996 (Begg et al. 1996). The statement has been updated several times since, and the latest version can be viewed on the CONSORT website (<http://www.consort-statement.org/home/>). The statement has been adopted by many scientific journals as it provides an extremely valuable reminder for authors about what items should be included in the report of their clinical trial.

The Effectiveness of Products Designed to Reduce Enamel Demineralization

Now that I have outlined some of the limitations of the research that has been carried out in this area I can summarize the evidence concerning the effectiveness of the two main methods of exposing the patient to either fluoride or CPP-ACP in preventing enamel demineralization during orthodontic treatment.

Fluoride

In 2004 I was the lead author for a Cochrane systematic review examining the effectiveness of different ways of delivering fluoride in the prevention of white spot demineralization during orthodontic treatment (Benson et al. 2004). We have recently updated this review to include any new studies that have been published since. Figure 10.1 is a flow-chart outlining the outcome for all the articles identified by searching of electronic databases, including the Cochrane Collaboration database created by hand searching the dental literature. It can be seen that 17 articles are included in the review, with 4 still awaiting more information and or data from the authors (see Box 10.2). Unfortunately, a quality assessment of each study showed that the majority are disadvantaged by one or more of the limitations expressed in the previous section. Just two studies, due to their design, provide the best evidence for the effectiveness of fluoride products in the prevention of demineralization during orthodontic treatment. A third well-designed study will be described that was not able to provide a definitive conclusion due to a large number of withdrawals and dropouts.

Comparison—Fluoride Varnish versus Nonfluoride Varnish

Caries-preventive Effectiveness of a Fluoride Varnish (Stecksén-Blicks et al. 2007) This was a double-blind, placebo-controlled, randomized clinical trial with two parallel groups.

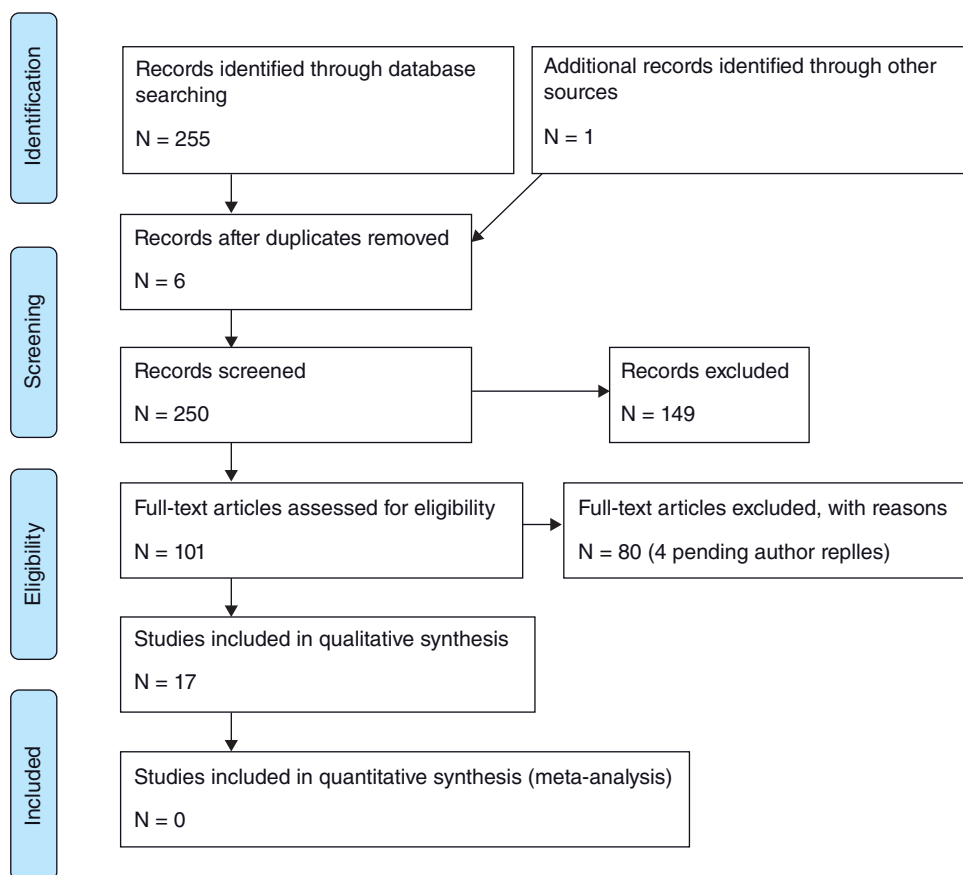


Figure 10.1 Flowchart for all the potential articles identified following the searches of the electronic databases (according to PRISMA guidelines, see <http://www.prisma-statement.org/index.htm>). For the full details of the electronic searches and search strategies undertaken please see Box 10.2.

The investigators recruited 273 consecutive orthodontic patients aged 12 to 15 years, who were randomly allocated to either the experimental or control groups. Participants in the experimental group received a topical application of a varnish containing 0.1% fluoride as difluorosilane in a polyurethane base (Fluor Protector, Ivoclar Vivadent, Schaan, Liechtenstein) at each appliance adjustment visit throughout their orthodontic treatment. Participants in the control group received an application of an identical placebo varnish, which contained no fluoride, at each adjustment visit. Both clinician and patient were masked with regard to group allocation. The presence and severity of demineralized white lesions were assessed from before and after digital photographs by two experienced and calibrated clinician judges who were also masked as to group allocation.

The authors were contacted to clarify some of the data presented in the article and were able to provide data in a format suitable for the calculation of a risk ratio (see Box 10.1). These are presented in Table 10.1. A graphical depiction of these data is presented

Box 10.2 Electronic Databases Searched and Details of Search Strategies Entered for Updated Cochrane Review (Benson et al. 2004) (March 2009)

OHG Trials Register Search Strategy

(orthodontic* AND (cariostatic* OR fluoride* OR naf OR “glass ionomer*” OR “cermet cement*” OR compomer* OR “composite resin”) AND (“dental enamel solubility” OR caries OR “dental fissures” OR deminerali* OR reminerali* OR decalcifi* OR “white spot”))

Central Search Strategy

- #1 MeSH descriptor Orthodontics explode all trees
- #2 orthodontic*
- #3 (#1 OR #2)
- #4 MeSH descriptor Sodium Fluoride explode all trees
- #5 MeSH descriptor Fluorides, Topical explode all trees
- #6 fluoride*
- #7 topical next fluoride*
- #8 NaF
- #9 MeSH descriptor Glass Ionomer Cements, this term only
- #10 glass next ionomer*
- #11 (#4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10)
- #12 MeSH descriptor Dental Enamel Solubility explode all trees
- #13 MeSH descriptor Tooth Demineralization explode all trees
- #14 reminerali* or deminerali* or decalcif*
- #15 white next spot*
- #16 (#12 OR #13 OR #14 OR #15)
- #17 (#3 AND #11 AND #16)

MEDLINE via OVID Search Strategy

1. exp ORTHODONTICS/
2. orthodontic\$.mp.
3. 1 or 2

4. exp SODIUM FLUORIDE/
5. exp FLUORIDES TOPICAL/
6. fluoride\$.mp.
7. (topical adj fluoride\$).mp.
8. NaF.ti.ab.
9. Glass Ionomer Cements/
10. (glass adj ionomer\$).mp.
11. 4 or 5 or 6 or 7 or 8 or 9 or 10
12. exp DENTAL ENAMEL SOLUBILITY/
13. TOOTH DEMINERALIZATION/
14. (reminerali\$ or deminerali\$ or decalcif\$).mp.
15. (white adj spot\$).mp.
16. 12 or 13 or 14 or 15
17. 3 and 11 and 16

Cochrane Search Filter for MEDLINE via OVID

Cochrane Highly Sensitive Search Strategy (CHSSS) for identifying randomized trials in MEDLINE: sensitivity maximizing version (2008 revision) as referenced in Chapter 6.4.11.1 and detailed in Box 6.4.c of *The Cochrane Handbook for Systematic Reviews of Interventions* Version 5.0.1 (updated September 2008).

1. randomized controlled trial.pt.
2. controlled clinical trial.pt.
3. randomized.ab.
4. placebo.ab.
5. drug therapy.fs.
6. randomly.ab.
7. trial.ab.
8. groups.ab.
9. or/1–8
10. animals.sh. not (humans.sh. and animals.sh.)
11. 9 not 10

EMBASE via OVID Search Strategy

1. exp ORTHODONTICS/
2. orthodontic\$.mp.
3. 1 or 2
4. exp SODIUM FLUORIDE/
5. exp FLUORIDES TOPICAL/
6. fluoride\$.mp.
7. (topical adj fluoride\$).mp.
8. NaF.ti,ab.
9. Glass Ionomer Cements/
10. (glass adj ionomer\$).mp.
11. 4 or 5 or 6 or 7 or 8 or 9 or 10
12. exp DENTAL ENAMEL SOLUBILITY/
13. TOOTH DEMINERALIZATION/
14. (reminerali\$ or deminerali\$ or decalcif\$).mp.
15. (white adj spot\$).mp.
16. 12 or 13 or 14 or 15
17. 3 and 11 and 16

Table 10.1 Data supplied by authors of the Stecksen-Blicks et al. (2007) to allow calculation of the risk ratio.

		Placebo Varnish	Fluoride Varnish	Total
Number of Patients with at Least One New Demineralized Lesion	Yes	80	26	106
	No	45	106	151
	Total	125	132	257

in the form of a forest plot (Figure 10.2). The graph shows that the risk ratio (0.31; 95% CI 0.21–0.44) favors the experimental material (fluoride varnish) and that the confidence interval does not cross the line of no difference, therefore confirming that there were significantly fewer new demineralized white lesions in the patients that had the application of the fluoride varnish at each visit compared with the placebo varnish.

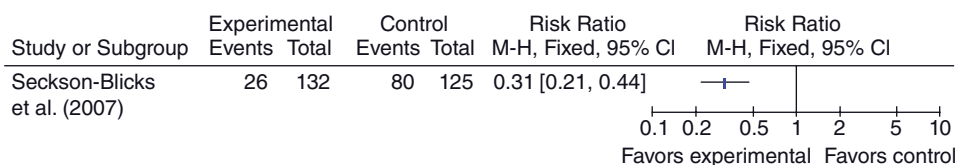


Figure 10.2 Forest plot study showing the risk ratio and 95% confidence intervals for the outcome number of new demineralized white lesions in experimental (fluoride varnish) and control (nonfluoride placebo varnish) patients in Steckslen-Blicks et al. (2007).

Table 10.2 Data supplied by authors of the Marcusson, Norevall & Persson (1997) to allow calculation of the risk ratio.

GIC			
Number of Patients with at Least One New Demineralized Lesion in the Experimental Quadrant			
Composite		Yes	No
Number of Patients with at Least One New Demineralized Lesion in the Control Quadrant	Yes	14	20
	No	7	19
14 + 20 + 7 + 19 = 60 patients			

Comparison—Glass Ionomer Cement versus Composite for Bonding Orthodontic Attachments

White Spot Reduction When Using Glass Ionomer Cement for Bonding in Orthodontics (Marcusson, Norevall & Persson 1997) This clinical trial compared a conventional GIC (AquaCem; DeTrey Dentsply GmbH, Konstanz, Germany) with a no-mix composite resin (Unite; Unitek, Monrovia, CA). The investigators used a split-mouth design on 60 consecutive patients aged between 11 and 19 years, with the experimental material being randomly assigned to either bonding the brackets in the upper or lower arch and the control material for bonding in the opposite arch. Assessments of demineralized white lesions were undertaken after the completion of orthodontic treatment (mean length of treatment 22 months). The number of new demineralized white lesions was assessed from pre- and posttreatment photographs by three judges using a 4-point scale. Disagreements were resolved by consensus, and an error analysis was carried out. The author was contacted to clarify a few issues, and although the method of allocation concealment was still not clear and there was no a priori sample size calculation or clear exclusion criteria, the study was well-designed and was assessed as having a low risk of bias.

In their article, the authors present their data without taking into account the clustering of teeth with an individual participants mouth (see the section Inappropriate Statistics below); however, we contacted the authors, and they were able to provide data in a format suitable for the calculation of a risk ratio (see Box 10.1). The data are presented in Table 10.2 and the risk ratio for a split-mouth study was calculated using the generic

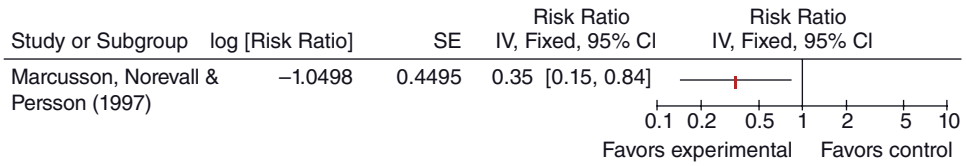


Figure 10.3 Forest plot study showing the risk ratio and 95% confidence intervals for the outcome number of new demineralized white lesions in experimental (conventional GIC) and control (conventional composite) quadrants in Marcusson, Norevall & Persson (1997).

inverse-variance method (RR 0.35; 95% CI 0.15–0.84). A graphical depiction of these data is presented in the form of a forest plot (Figure 10.3). The graph shows that the risk ratio favors the experimental material (conventional GIC) and that the confidence interval does not cross the line of no difference; therefore there are statistically fewer new demineralized lesions in the arches bonded with the GIC compared to arches bonded with the composite material.

As stated previously, a split-mouth study is an inappropriate design for determining the effectiveness of a fluoride-containing product in preventing demineralization, as the material may be disadvantaged if there is crossover of fluoride from the experimental quadrant to the control quadrant. In spite of this, the result of this trial was statistically significant. Unfortunately, in another article the authors of the same study showed that the conventional glass ionomer cement had a significantly increased (both statistically and clinically) higher number of bond failures compared to the conventional composite (Norevall, Marcusson & Persson 1996). Since this study was undertaken, resin-modified GIC has been introduced for use in orthodontic patients. This is considerably stronger than conventional GIC; however, there are no published studies comparing the incidence of new demineralized lesions over the full course of orthodontic treatment when bonding brackets with resin-modified GIC compared to composite.

Comparison—Fluoride-Releasing Glass Beads versus Fluoride Mouth Rinse

Fluoride-Releasing Glass Beads in Orthodontic Treatment to Reduce Decay (Luther et al. 2005) This was a prospective, longitudinal, randomized clinical trial with two parallel groups. The investigators recruited 70 patients aged 11 to 45 years about to start treatment with fixed orthodontic appliances. They were randomly allocated to either the experimental or control groups. Participants in the experimental group received a small (4 mm × 4 mm), carbonate-based glass bead containing 13.3% fluoride, which was attached to the archwire or upper molar band (Figure 10.4). Participants in the control group were supplied with a fluoride mouth rinse (0.05% w/v NaF) and instructed to use it once a day.

Assessments of demineralized white lesions were undertaken after the completion of orthodontic treatment using standardized, pretreatment and posttreatment, cross-polarized, color photographic images of the upper six front teeth. The photographic images were digitized, and demineralized white lesions were measured using computerized image analysis by one masked assessor. An estimate of repeatability was determined.

Unfortunately, the trial suffered a high number of withdrawals and dropouts partly due to breakage and loss of the glass bead. There were also a large number of participants with



Figure 10.4 Fluoride-releasing glass bead placed on the orthodontic archwire (photograph supplied with the kind permission of Professor Jack Toubma).

Table 10.3 Data derived from Luther et al. (2005) (confirmed by authors) allowing calculation of the risk ratio.

		Fluoride Mouth Rinse	Fluoride-Containing Glass Bead	Total
Number of Patients with at Least One New Demineralized Lesion	Yes	6	8	17
	No	13	10	20
	Total	19	18	37

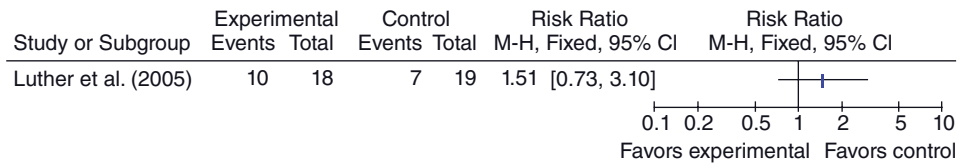


Figure 10.5 Forest plot study showing the risk ratio and 95% confidence intervals for the outcome number of new demineralized white lesions in experimental (fluoride-containing glass beads) and control (fluoride mouth rinse) patients in Luther et al. (2005).

incomplete records, which highlights how difficult it is sometimes to coordinate a clinical trial. The authors were contacted to clarify some of the data, which are presented in Table 10.3 and graphically represented in Figure 10.5. This shows that there was no statistically significant difference in the number of patients with new demineralized white lesions between two groups (RR 1.41; 95% CI 0.61–3.26). The result is disappointing as the use of fluoride-releasing glass bead would seem an ideal way of exposing the orthodontic patient to a consistent and low-level of fluoride throughout their treatment that does not

rely upon their compliance. The interpretation of this null outcome is difficult due to large number of patients whose data were missing, and further studies are being undertaken.

Casein Phosphopeptide-Amorphous Calcium Phosphate

Two systematic reviews have recently examined the evidence for the use of casein products and CPP-ACP in dentistry. One specifically looked at the effectiveness of CPP-ACP in preventing caries (Yengopal & Mickenautsch 2009), whereas the other was more general (Azarpazhooh & Limeback 2008). Between the two reviews, 15 studies of reasonable quality were identified. Although several studies involved nonorthodontic volunteers who were wearing removable appliances containing enamel samples that were removed and measured for mineral loss and lesion depth at various time periods, only one of the included studies was carried out in actual orthodontic patients, and these were posttreatment. Therefore, there are no studies examining the effectiveness of CPP-ACP products in the reduction of demineralized white lesions in orthodontic patients during treatment.

Summary

There are a number of products containing fluoride and CPP-ACP available to clinicians and their patients. Unfortunately the evidence for the effectiveness of these products is weak. The research that has been carried out is often undermined by poor study design, insufficient experimental length, and inappropriate statistics. As we enter the second decade of the new millennium, it is time for researchers to undertake the clinical trials necessary to start answering the question “What is the best way of preventing demineralization during orthodontic treatment?”

Acknowledgments

My thanks go to all the staff at the Cochrane Oral Health Review Group for their continued help and advice. In particular I thank Ann Littlewood who carried out the electronic searches for the updated review and Helen Worthington for her help with the statistical analysis.

References

- Azarpazhooh, A. & Limeback, H., 2008. Clinical efficacy of casein derivatives: a systematic review of the literature. *Journal of the American Dental Association* 139, pp. 915–924.
- Begg, C., Cho, M., Eastwood, S. et al., 1996. Improving the quality of reporting of randomized controlled trials. The CONSORT statement. *Journal of the American Medical Association* 276, pp. 637–639.
- Benson, P.E., Parkin, N., Millett, D.T. et al., 2004. In *The Cochrane Database of Systematic Reviews*. Chichester, UK: John Wiley & Sons.
- Dean, H.T., Arnold, F.A., Jr., Jay, P. et al., 1950. Studies on mass control of dental caries through fluoridation of the public water supply. *Public Health Rep* 65, pp. 1403–1408.

- Gorton, J. & Featherstone, J.D., 2003. In vivo inhibition of demineralization around orthodontic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics* 123, pp. 10–14.
- Hellwig, E. & Lennon, A.M., 2004. Systemic versus topical fluoride. *Caries Research* 38, pp. 258–262.
- Luther, F., Tobin, M., Robertson, A.J. et al., 2005. Fluoride-releasing glass beads in orthodontic treatment to reduce decay: a randomized, controlled clinical trial. *World Journal of Orthodontics* 6 (Suppl), pp. 166–167.
- Marcusson, A., Norevall, L.I. & Persson, M., 1997. White spot reduction when using glass ionomer cement for bonding in orthodontics: a longitudinal and comparative study. *European Journal of Orthodontics* 19, pp. 233–242.
- Mitchell, L., 1992. Decalcification during orthodontic treatment with fixed appliances—an overview. *British Journal of Orthodontics* 19, pp. 199–205.
- Norevall, L.I., Marcusson, A. & Persson, M., 1996. A clinical evaluation of a glass ionomer cement as an orthodontic bonding adhesive compared with an acrylic resin. *European Journal of Orthodontics* 18, pp. 373–384.
- Pascotto, R.C., Navarro, M.F., Capelozza Filho, L. & Cury, J.A., 2004. In vivo effect of a resin-modified glass ionomer cement on enamel demineralization around orthodontic brackets. *American Journal of Orthodontics and Dentofacial Orthopedics* 125, pp. 36–41.
- Reynolds, E.C., 1997. Remineralization of enamel subsurface lesions by casein phosphopeptide-stabilized calcium phosphate solutions. *Journal of Dental Research* 76, pp. 1587–1595.
- Stecksen-Blicks, C., Renfors, G., Oscarson, N.D. et al., 2007. Caries-preventive effectiveness of a fluoride varnish: a randomized controlled trial in adolescents with fixed orthodontic appliances. *Caries Research* 41, pp. 455–459.
- ten Cate, J.M., 1997. Review on fluoride, with special emphasis on calcium fluoride mechanisms in caries prevention. *European Journal of Oral Sciences* 105, pp. 461–465.
- Yengopal, V. & Mickenautsch, S., 2009. Caries preventive effect of casein phosphopeptide-amorphous calcium phosphate (CPP-ACP): a meta-analysis. *Acta Odontologica Scandinavica* 67, pp. 321–332.

Invisalign Therapy—A Systematic Review of Lower Quality Evidence

Jason M. Bressler¹, DDS, BS, **Stefanie Hamamoto²**, DDS,
Gregory J. King³, DMD, DMSc, **Anne-Marie Bollen⁴**, DDS,
MS, PhD

¹Research Associate, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Washington

²Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Washington

³Moore Reidel Professor, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Washington

⁴Professor of Orthodontics, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Washington

Introduction

Positioners and tooth aligners have long histories of use by orthodontists to achieve minor corrections. However, using computer-assisted design and manufacturing technologies, several companies (e.g., Invisalign) have been able to provide a service that has made the approach feasible for a wider variety of corrections and patients than was previously possible. In addition to orthodontists, these services have been intensely marketed to nonspecialists and even directly to the public. The latter efforts have placed clinicians in the position of needing to become familiar not only with the evidence that supports the various

strategies employed in treating malocclusions with these appliances but also with the evidence related to its effectiveness, risks, and benefits compared to no treatment or standard treatment with fixed appliances. A recent systematic review (Lagravere & Flores-Mir 2005) found only two studies that met their inclusion criteria (randomized clinical trials [RCTs]) and therefore could only state that “... no strong conclusions could be made regarding the treatment effects of Invisalign appliances. Future prospective randomized clinical trials are required to support, with sound scientific evidence, the claims about Invisalign’s treatment effects. Clinicians will have to rely on their Invisalign clinical experience, the opinions of experts and the limited published evidence when using Invisalign appliances.”

The purpose of this study is to update this systematic review and also to include an analysis of the lower-quality evidence. The latter would demonstrate how useful data could be extracted from these types of studies while providing further guidance for evidence-based practice.

Methods

Searches

A search strategy was developed for MEDLINE and revised appropriately for other databases, i.e., Web of Science, EMBASE, and Cochrane. The search terms were *Invisalign*, *malocclusion*, *aligners*, and *clear appliances/braces*. Searches covered 1966–August 2009. Ninety-three articles were retrieved from these searches (Figure 11.1). Two authors (JB and SH) independently reviewed the titles and abstracts of these papers, and discrepancies were resolved by further review and discussion with the other authors (GK and AB). Seven papers were found to be duplicates and were eliminated, reducing the number to 86. All abstracts were read to determine if they met inclusion/exclusion criteria and discrepancies resolved as described above. Excluded were letters/commentaries, expert opinions and gray literature (i.e., continuing dental education and conference presentations without published abstracts and unpublished reports with or without industry sponsorship). Included were all published reports (i.e., systematic reviews, RCTs, cohort and cross-sectional studies, case-control studies, case series, and case reports). Forty-nine more papers were excluded based on these criteria, leaving a total of 37 articles that were reviewed in full. The bibliographies of these articles were also scrutinized for further

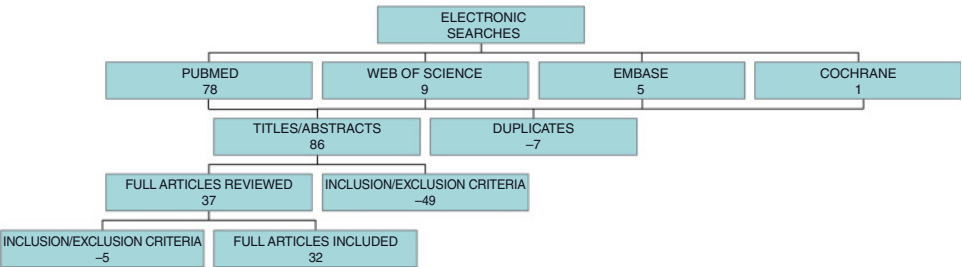


Figure 11.1 Search summary.

relevant articles. After full text review, 5 more articles were excluded based on the selection criteria. Data were then extracted from the remaining 32 articles.

Data Collection

All papers were categorized by experimental design. Systematic reviews, RCTs, and cohort and cross-sectional studies were examined for aims and conclusions, noting the sample sizes (see Tables 11.1 and 11.2). Because of the heterogeneity of their aims and methods and the small numbers of studies in these categories, it was not possible to conduct further data extraction from them.

All case reports and case series were examined for type(s) of malocclusions treated. It was also possible to note the treatment time and the requirement to use adjunctive procedures to achieve the reported results. We used the Index of Complexity, Outcome and Need (ICON) (Daniels & Richmond 2000) to assess the complexity of these cases. One blinded investigator (GK), who was trained by the developer of the ICON (Stephen Richmond) and successfully scored a set of 30 models with known scores, which is used as a calibration set. He was able to score these using the initial records presented in these articles. Blinding was done by one author (JB), selecting and coding the initial photographs from each article.

The ICON has been validated based on the subjective judgments of 97 orthodontists from nine countries on 240 initial and 98 treated study models. Intra-oral photographs can also be used to satisfactorily score malocclusion using the ICON. The index was created as a single measure of treatment need, complexity and outcome. ICON has two advantages in this context. It has an esthetic component that is weighted highly by clinicians and valued by patients, and it has clear and internationally validated cut points for treatment need and outcome with categories for complexity and improvement. Five weighted measurements—dental esthetics, crossbite, anterior vertical relationship, upper arch crowding/spacing, and buccal segment anteroposterior relationship—compose the components of the ICON. These weighted scores are summed to derive a total score used in analyses. The components were individually scored from the publication photographs and multiplied by their respective weights to yield a single summary ICON score. The median and standard deviations of these scores were calculated. The final scores also were used to determine pretreatment case complexity (easy = <29; mild = 29–50; moderate = 51–63; difficult = 64–77; very difficult = >77). The prevalence of cases in each of these categories was then calculated and the distribution displayed in a histogram (Figure 11.2).

The primary outcome for this project was the effectiveness of Invisalign in correcting malocclusions. This included the measures cited (i.e., case complexity, treatment time, need for other treatment approaches, and stability). The secondary outcomes included quality of life, pain, periodontal considerations, and root resorption. The latter were done qualitatively because there were few reported quantitative data and the numbers of studies addressing these criteria were few.

Results

Seven of the 32 articles reviewed for this study had research designs that are generally considered to provide the highest-quality evidence (Table 11.1). One systematic review

Table 11.1 Systematic reviews and randomized controlled trials.

ID	Study (Ss)	Aim of Study	Outcome
Lagravere & Flores-Mir (2005)	SR (2 Studies reviewed)	Evaluate treatment effects of Invisalign	• RCTs only • No strong conclusions can be made regarding the treatment effects of Invisalign
Baldwin, King & Ramsay (2008)	RCT* (24)	Describe the movement of teeth adjacent to premolar extraction sites during space closure with clear aligners and fixed appliances	• Dental tipping occurs with clear aligner treatment • Tipping can be corrected with fixed appliances
Bollen, Huang & King (2003)	RCT* (51)	Effects of activation time and material stiffness on aligner treatment	• 2-Week activation times lead to higher success than 1 week • No difference between hard or soft material • Premolar extractions decrease treatment success
Clements, Bollen & Huang (2003)	RCT* (51)	Evaluate effects of material stiffness and frequency of appliance change on the quality of improvement of malocclusion	• Anterior alignment was most improved • Incisor extraction sites had the greatest amount of closure
Miethke & Brauner (2007)	RCT** (30)	Evaluation of periodontal health with Invisalign compared to fixed appliances	• Increased periodontal health with Invisalign
Miethke & Vogt (2005)	RCT** (30)	Evaluation of periodontal health with Invisalign compared to fixed lingual appliances	• Lower periodontal risk for Invisalign
Barbagallo, Jones & Petocz (2008)	RCT (27) Total subjects: 108	Evaluation of root resorption following aligner treatment	• Aligners have similar effects on root cementum as light forces with fixed appliances

*Multiple reports from one patient pool.

**Multiple reports from one patient pool.

Table 11.2 Cohort and cross-sectional studies.

ID	Design (Subjects)	Aim of Study	Outcome
Miller, McGorray & Womack (2007)	Cohort (60)	Compare Invisalign and fixed during the 1 st week of treatment	• Less pain and fewer negative impacts
Djeu, Shelton & Maganzini (2005)	Cohort (95)	Compare treatment outcomes from Invisalign and conventional fixed appliances	• Invisalign < fixed • Invisalign weakness: large AP discrepancies • Invisalign strengths: space closure, anterior rotations, marginal ridge heights
Kuncio, Maganzini & Shelton (2007)	Cohort (22)	Compare postretention dental changes between Invisalign and conventional fixed appliances	• More relapse with patients treated with Invisalign
Lingenbrink, King & Bollen (2002)	Cross-sectional (105)	Compare quality of life measures from patients treated with clear removable appliances and conventional fixed orthodontics	• No differences in comfort, performance or pain • Clear aligners had fewer problems with food adherence to appliances and had fewer dietary restrictions

(Continued)

Table 11.2 Cohort and cross-sectional studies. (*Continued*)

ID	Design (Subjects)	Aim of Study	Outcome
Duong & Kuo (2006)	Cohort (20)	Evaluate finishing with Invisalign	• Finishing often requires additional aligners and detailing pliers
Kravitz, Kusnoto & BeGole (2009)	Cohort (37)	Evaluate efficacy of tooth movement with Invisalign	• Mean accuracy compared to planned: 41% • Most accurate movement: lingual constriction
Kravitz, Kusnoto & Agran (2008)	Cohort (31)	Evaluate attachments and IPR on canine rotations with Invisalign	• Attachments and IPR do not improve canine rotation
Nedwed & Miethke (2005)	Cohort (54)	Evaluate patient acceptance and impairment by Invisalign	• High acceptance and minimal impairment • Should be considered as an alternative to lingual brackets for esthetically demanding patients
Vlaskalic & Boyd (2002)	Cohort (40)	Evaluate 3-D Invisalign Digital Technology and its clinical efficiency	• Mild to moderate malocclusions may benefit from Invisalign
Meier, Wiemer & Miethke (2003)	Cross-sectional (89)	Produce a profile of patients that are interested in Invisalign treatment	• Females between 20–29 • 97% for esthetics • Fixed rejected
Total Subjects: 553			

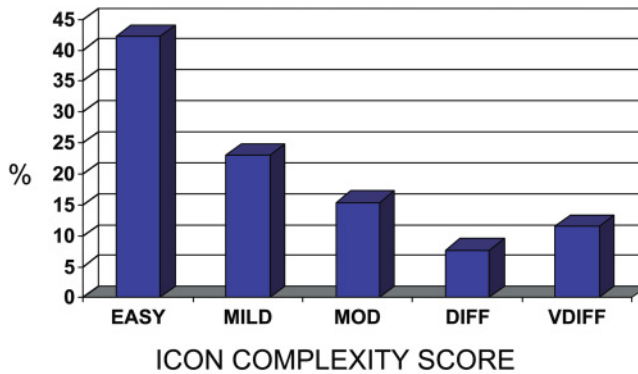


Figure 11.2 Percent of cases in Table 11.3 by complexity category (ICON).

was identified. Because this study only included RCTs, and these were relatively rare, the authors could only conclude that the evidence was inadequate and thus was not much use as an evidence base for practice (Lagravere & Flores-Mir 2005).

The six papers with RCT designs actually consisted of only three groups of patients. One RCT had a total of 51 patients (Baldwin, King & Ramsay 2008; Bollen, Huang & King 2003; Clements, Bollen & Huang 2003) comparing differing strengths of thermo-plastic material and reactivation schedules. These papers reported no difference in outcome (i.e., need to retrack the planned treatment schedule) based on the materials used and that a 2-week reactivation scheme was more effective than 1. The study also found that Invisalign was effective at aligning anterior teeth and closing anterior extraction spaces, but premolar extraction cases were less successful, and a subset of the patients requiring premolar extraction ($n = 24$) experienced significant amounts of dental tipping around extraction sites (Baldwin, King & Ramsay 2008). The latter could be recovered, however, with fixed-appliance treatment. The second RCT was represented by two papers with 30 patients (Miethke & Brauner 2007; Miethke & Vogt 2005). This study found that Invisalign patients had fewer periodontal problems than fixed appliances. The third study had 27 subjects (Barbagallo, Jones & Petocz 2008) and found that Invisalign treatment had cemental cratering comparable to that from light-force fixed appliances.

There were 10 studies that employed either cohort or cross-sectional designs (Table 11.2). Four of these studies compared fixed treatment with Invisalign at several stages (Djeu, Shelton & Maganzini 2005; Kuncio, Maganzini & Shelton 2007; Lingenbrink, King & Bollen 2002; Miller, McGorray & Womack 2007). Miller and coworkers (Miller, McGorray & Womack 2007) found that Invisalign was less painful than fixed after 1 week ($n = 60$). Using the American Board of Orthodontists (ABO) Objective Grading System, Djeu et al. (2005) assessed immediate posttreatment outcomes on 95 patients and found that Invisalign cases generally didn't finish as well as fixed appliance cases but was more effective with space closure, anterior rotations, and aligning marginal ridge heights. Using the same approach, Kuncio and coworkers (2007) found that Invisalign patients ($n = 22$) tended to relapse more than those treated with fixed appliances. Using a questionnaire, Lingenbrink et al. (2002) compared some quality of life measures between the two appliances in patients who had been in treatment for a period of several months ($n = 105$). They

Table 11.3 Characteristics of each case published as a case report or in a case series.

Reference	Malocclusion	Months in Treatment	ICON Score	ICON Complexity Category	Secondary Procedures	Invisalign Retrack Months
Turatti, Womack & Bracco 2006	Extruded maxillary incisors	11	43	MI		
Womack 2006	Severe maxillary and mandibular crowding	24	77	D	ATT	4
Giancotti & Ronchin 2006	Deep bite, mandibular spacing, maxillary molar supraeruption	13	19	E	E	
Giancotti, Mampieri & Greco 2008	Deep bite, maxillary and mandibular crowding	15	24	E	IPR	6
Giancotti, Mampieri & Greco 2008	Deep bite, maxillary and mandibular crowding	16	61	MO	IPR	5
Giancotti, Mampieri & Greco 2008	Deep bite, mandibular crowding	17	35	MI		
Boyd 2007	Class II Div I, maxillary prognathic/mandibular retrognath, 13-mm overjet, 7-mm overbite	14.5	88	VD	ATT	
Boyd 2007	Rotated canines, severe overbite, maxillary central supraeruption	18	59	MO	ATT	
Boyd 2007	Open bite, maxillary and mandibular crowding	31	90	VD	IPR ATT	
Boyd 2007	Class II Div I, 3-mm overbite, 7-mm overjet, maxillary and mandibular crowding	25	23	E	IPR ATT	6
Womack & Day 2008	Class II Div II, β retrognathic mandibular	8	59	MO	IPR	6
Brezniak & Wasserstein 2008	Class III maxillary and mandibular crowding, crossbite maxillary laterals	14	79	VD	IPR	
Giancotti, Greco & Mampieri 2006	Class II, deep bite, severe maxillary and mild mandibular crowding	NR	69	D	IPR FX	
Vlaskalic & Boyd 2001	Class III molar, maxillary and mandibular crowding, edge-edge overbite and overjet	24	27	E		

Choi, Park & Jo 2009	Anterior open bite, mild maxillary and mandibular crowding, maxillary and mandibular incisor protrusion	21	28	E	MS
Chenin, Trosien & Fong 2003	Mild maxillary and moderate mandibular crowding, deep overbite	8 Mx 12 Mn	13	E	IPR
Chenin, Trosien & Fong 2003	Maxillary and mandibular crowding	16 Mx 21 Mn	32	MI	IPR
Chenin, Trosien & Fong 2003	Maxillary and mandibular crowding, maxillary lateral in crossbite	6 Mx 12 Mn	20	E	ATT
Bishop, Womack & Derakhshan 2002	Maxillary spacing and mandibular crowding, moderate overbite	7 Mx 9 Mn	31	MI	IPR
Bishop, Womack & Derakhshan 2002	Maxillary spacing and mandibular crowding, mandibular canine rotated	10	27	E	IPR
Miller, Duong & Derakhshan 2002	Mandibular crowding	11	20	E	
Boyd 2008	Moderate maxillary and mandibular crowding	8	29	MI	IPR
Boyd 2008	Class II Div I, moderate maxillary and mandibular crowding, deep overbite	13	27	E	ATT
Boyd 2008	Class II Div I, moderate maxillary and mandibular crowding, moderate overbite	NR	27	E	
Boyd 2005	Class III mandibular prognathic, post crossbite, \$-1-mm overbite, 0-mm overjet, moderate mandibular crowding	18	39	MI	FX
Boyd 2005	Moderate maxillary and mandibular crowding, bilateral post crossbite, 2-mm anterior crossbite, 2-mm reverse crossbite	27	61	MO	FX
Median Icon Score (<i>n</i> = 26) (standard deviation)			31.5 (23.3)		

ICON complexity categories: E, easy; MI, mild; MO, moderate; D, difficult; VD, very difficult.

Secondary procedures: ATT, attachments; IPR, interproximal reduction; E, intermaxillary elastics; MS, miniscrews; FX, fixed appliances.

Mx, maxillary; Mn, mandibular, NR, not reported.

reported that the patients perceived little difference in comfort, pain, or performance between the two appliances but that the Invisalign patients had fewer oral hygiene or dietary complaints.

Of the 32 retrieved articles, 15 were case reports or case series (Table 11.3) representing 26 treated patients who presented with a variety of orthodontic problems. The treatment durations varied considerably (range: 8–31 months) as did their initial ICON complexity scores (range: 13–90). The median and standard deviation for the latter were 31.5 and 23.3, respectively. Based on an the validated ICON assessment criteria, this score is considered to represent malocclusions of mild complexity (Daniels & Richmond 2000). Despite all levels of complexity being represented in these cases, the distribution is skewed in favor of the easy to mild categories (Figure 11.2). Moreover, there does not seem to be a positive association between treatment duration and case complexity. To illustrate, the most complex case took the longest time (ICON = 90; 30 months), but the next most complex case (ICON = 88) took only 14.5 months (Boyd 2007). Conversely, cases that scored as easy had treatment durations ranging between 10 and 25 months. The most common secondary treatments were interproximal reduction (12), followed by the use of attachments (7), Invisalign retracking (5), and fixed appliances (3). Only two cases required elastics or miniscrews (1 each).

Discussion

The 32 articles examined in this review constitute treatment results from all types of research designs. The preponderance of cases were treated as part of cohort/cross-sectional studies (553), followed by RCTs (108) and case reports/case series (26), in that order. This fact, along with a body of literature containing only three separate RCTs, suggests that the quality of the evidence on this topic is only moderate. Despite the largest number of publications being case reports, these actually constitute only a small part of the total number of patients examined (i.e., 26 separate cases).

Two of the RCTs considered potential adverse sequelae of the appliance, that is, periodontal (Miethke & Brauner 2007; Miethke & Vogt 2005) and root resorption (Barbagallo, Jones & Petocz 2008). The former found that Invisalign patients had better periodontal health than those treated with fixed appliances, and the latter reported no difference in cemental cratering between Invisalign and light-force fixed appliances. These findings probably reflect the fact that the patient can remove Invisalign appliances, allowing better oral hygiene and periods of tissue recovery.

The third RCT (Bollen, Huang & King 2003; Clements, Bollen & Huang 2003) compared two materials of differing stiffness and two reactivation schedules (1 and 2 weeks) with the primary end point being an inability to proceed with the planned sequence of aligners. Aligner stiffness had little effect on that outcome, and the longer reactivation scheme was more successful than the shorter. Because half of the patients in this trial included premolar extraction cases, a follow-up study of that subset (Baldwin, King & Ramsay 2008) found tipping of teeth adjacent to premolar extraction sites to be prevalent.

Of the 10 cohort/cross-sectional studies, 4 compared outcomes between Invisalign treatment and conventional fixed appliances. These studies suggest that Invisalign is less painful than fixed appliances during the first week of treatment (Miller, McGorray &

Womack 2007) and generally has less-acceptable outcomes (Djeu, Shelton & Maganzini 2005) and more relapse potential (Kuncio, Maganzini & Shelton 2007). Lingenbrink and coworkers (2002) compared quality of life in a cross-sectional study designed to compare Invisalign with fixed patients at midtreatment. They found little difference except for the former reporting fewer problems with maintaining good oral hygiene and fewer dietary restrictions. Once again, these Invisalign advantages in quality of life probably reflect the appliance's being removable by the patients.

The remaining 6 cohort/cross-sectional studies constitute various aspects of case selection and product development. It is noteworthy that, after more than a decade on the market, the clinicians who use the Invisalign system still seem to be learning how to best use it. These studies involved finishing procedures (Duong & Kuo 2006), predictability (Kravitz, Kusnoto & BeGole 2009), effectiveness of adjunctive procedures in tooth movement (i.e., interproximal reduction and attachments) (Kravitz, Kusnoto & Agran 2008), and usefulness of 3-D imaging in treatment (Vlaskalic & Boyd 2002). Two studies examined case selection and patient acceptance (Nedwed & Miethke 2005; Meier, Wiemer & Miethke 2003).

Although case reports and case series constituted almost half (15/32) the papers examined for this review, they only represented 26 patients. These treatments include a wide variety of malocclusions. However, despite representing all categories of ICON treatment complexity, most had scores in the easy or mild categories. This may represent limitations of treatment with this appliance as presently being practiced, selection bias in favor of reporting easier cases with good outcomes, or a combination of these factors. The treatment times were highly variable but seem to be comparable to those with fixed treatment and somewhat reflective of the selection in favor of less-complicated cases. Most patients (21/26) required the use of some type of procedure adjunctive to Invisalign, with the most common being interproximal reduction and use of attachments.

Well-conceived and implemented comparative studies exist on effectiveness, adverse sequelae (i.e., periodontal, root resorption, and relapse), and patient-centered outcomes of Invisalign. Cost-effectiveness analyses comparing Invisalign to conventional fixed appliance treatment from the perspective of the orthodontist and the patient are lacking. The orthodontist often finds Invisalign appealing because it requires less chair time. However, the laboratory costs and issues related to communicating with a remote service laboratory can be important considerations, as are the possible limitations of the approach in producing high-quality, stable results for the patient. The adult patient also finds Invisalign treatment appealing because of its esthetic, comfort, and hygiene advantages over conventional fixed appliances. In making an informed decision about selecting Invisalign for their treatment, patients need to consider the possibilities of added costs and reduced effectiveness compared to conventional approaches. Multiple adjunctive approaches have been reported and are recommended for various clinical situations. Likewise, most types of malocclusion have been attempted with variable amounts of success.

What can we conclude from this study about the value of including lower levels of evidence in systematic reviews? When viewed as a body of evidence, the case reports and case series demonstrated what was *possible*—general proof of principle. Due to small sample size and high risk of bias, they did not provide data on what is *probable* under usual clinical circumstances. Systematically examining the low levels of evidence on the topic of Invisalign provided at least two further insights. (1) Although tending to be easier cases with highly favorable outcomes, results generally seemed to reflect the more rigorous

studies: there was no evidence of adverse periodontal or root resorption sequelae; treatment times were variable but similar to conventional appliances; there were no reports of patient dissatisfaction; and various adjunctive approaches seem to be necessary to achieve good results. (2) Because the lower levels of evidence serve to inform the design of higher-level studies, the systematic review of the lower levels of evidence on Invisalign provided a clearer picture of what future studies would be appropriate and needed. In this instance, future studies should include comparative studies on treatment efficiency and cost-effectiveness from patient and practitioner perspectives; examination of outcomes from more complex cases; and the indications for and utility of various adjuncts. These studies would seem to be important additions to the evidence base for Invisalign treatment.

Conclusions

The efficiency and usefulness of new treatment approaches, such as Invisalign, need to be validated through independent clinical studies. Ideally, studies with the highest level of evidence (RCTs) should be adopted whenever possible. In the absence of these more rigorous study designs, information can be obtained from available reports of lower quality, especially if these are viewed as a single body of evidence. In the systematic review on Invisalign treatment reported here, the studies of the lowest levels of evidence support many of the findings of the studies with higher-level research designs. While Invisalign treatment has been attempted for most types of malocclusion, most of the reports of successful treatment are from easier cases. Moreover, Invisalign alone does not seem to be adequate to achieve high-quality results but rather requires multiple adjunctive approaches for various clinical situations.

It is clear that there is a great need for more studies designed to model variables with respect to treatment efficiency and outcome quality. This would be central to improving treatment and selection of the most favorable cases to treat with this appliance.

Acknowledgments

The authors wish to thank Drs. Mark Drangsholt and Linda LeResche and Ms. Terry Jankowski for their support and advice in the conduct of this research. The research was supported by NIH grant R25 DE 018436.

References

- Baldwin, D., King, G., Ramsay, D. et al., 2008. Activation time and material stiffness of sequential removable orthodontic appliances. Part 3: premolar extraction patients. *American Journal of Orthodontics and Dentofacial Orthopedics* 133, pp. 837–845.
- Barbagallo, L., Jones, A., Petocz, P. et al., 2008. Physical properties of root cementum. Part 10: Comparison of the effects of invisible removable thermoplastic appliances with light and heavy orthodontic forces on premolar cementum. A micorcomputed-tomography study. *American Journal of Orthodontics and Dentofacial Orthopedics* 133, pp. 218–227.
- Bishop, A., Womack, R. & Derakhshan, M., 2002. An esthetic and removable orthodontic treatment option for patients: Invisalign. *The Dental Assistan* 71, pp. 14–17.

- Bollen, A., Huang, G., King, G. et al., 2003. Clinical evolution of the Invisalign appliance. Part 1: ability to complete treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 124 pp. 496–501.
- Boyd, R., 2005. Surgical-orthodontic treatment of two skeletal Class III patients with Invisalign and fixed appliances. *Journal of Clinical Orthodontics* 39, pp.245–258.
- Boyd, R., 2007. Complex orthodontic treatment using a new protocol for the Invisalign appliance. *Journal of Clinical Orthodontics* 41, pp. 525–547.
- Boyd, R., 2008. Esthetic orthodontic treatment using the Invisalign appliance for moderate to complex malocclusions. *Journal of Dental Education* 72, pp. 948–967.
- Brezniak, N. & Wasserstein, A., 2008. Root resorption following treatment with aligners. *The Angle Orthodontist* 78, pp. 1119–1124.
- Chenin, D., Trosien, A., Fong, P. et al., 2003. Orthodontic treatment with a series of removable appliances. *Journal of the American Dental Association* 134, p. 1322.
- Choi, N., Park, Y., Jo, Y. et al., 2009. Combined use of miniscrews and clear appliances for the treatment of bialveolar protrusion without conventional brackets. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, pp. 671–681.
- Clements, K., Bollen, A., Huang, G. et al., 2003. Activation time and material stiffness of sequential removable orthodontic appliances. Part 2: Dental improvements. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 502–508.
- Daniels, C. & Richmond, S., 2000. The development of the index of complexity, outcome and need (ICON). *Journal of Orthodontics* 27, pp. 149–162.
- Djeu, G., Shelton, C. & Maganzini, A., 2005. Outcome assessment of Invisalign and traditional orthodontic treatment compared with the American Board of Orthodontics objective grading system. *American Journal of Orthodontics and Dentofacial Orthopedics* 128, pp. 292–298.
- Duong, T. & Kuo, E., 2006. Finishing with Invisalign. *Progress in Orthodontics* 7, pp. 44–55.
- Giancotti, A., Greco, M. & Mampieri, G., 2006. Extraction treatment using Invisalign technique. *Progress in Orthodontics* 7, pp. 32–43.
- Giancotti, A., Mampieri, G. & Greco, M., 2008. Correction of deep bite in adults using the Invisalign system. *Journal of Clinical Orthodontics* 42, pp. 719–726.
- Giancotti, A. & Ronchin, M., 2006. Pre-restorative treatment with the Invisalign system. *Journal of Clinical Orthodontics* 40, pp. 679–682.
- Kravitz, N., Kusnoto, B., Agran, B. et al., 2008. Influence of attachments and interproximal reduction on the accuracy of canine rotation with Invisalign. A prospective clinical study. *The Angle Orthodontist* 78, pp. 682–687.
- Kravitz, N., Kusnoto, B., BeGole, E. et al., 2009. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, pp. 27–35.
- Kuncio, D., Maganzini, A., Shelton, C. et al., 2007. Invisalign and traditional orthodontic treatment postretention outcomes compared using the American Board of Orthodontics objective grading system. *The Angle Orthodontist* 77, pp. 864–869.
- Lagravere, M. & Flores-Mir, C., 2005. The treatment effects of Invisalign orthodontic aligners—a systematic review. *Journal of the American Dental Association* 136, pp. 1724–1729.
- Lingenbrink, J., King, G. & Bollen, A., 2002. Quality of life comparison between clear removable and conventional orthodontics. *Journal of Dental Research* 81, p. A463.
- Miethke, R. & Brauner, K., 2007. Comparison of the periodontal health of patients during treatment with the Invisalign system and with fixed orthodontic appliance. *Journal of Orofacial Orthopedics* 68, pp. 223–231.
- Miethke, R. & Vogt, S., 2005. A comparison of the periodontal health of patients during treatment with the Invisalign system and with fixed orthodontic appliances. *Journal of Orofacial Orthopedics* 66, pp. 219–229.
- Meier, B., Wiemer, K. & Miethke, R., 2003. Invisalign—patient profiling. Analysis of a prospective survey. *Journal of Orofacial Orthopedics* 64, pp. 352–358.

- Miller, R., Duong, T. & Derakhshan, M., 2002. Lower incisor extraction treatment with the Invisalign system. *Journal of Clinical Orthodontics* 36, pp. 95–102.
- Miller, K., McGorray, S., Womack, R. et al., 2007. A comparison of treatment impacts between Invisalign aligner and fixed appliance therapy during the first week of treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 131(3), 302e pp. 301–309.
- Nedwed, V. & Miethke, R., 2005. Motivation, acceptance and problems of Invisalign patients. *Journal of Orofacial Orthopedics* 66, pp. 162–173.
- Turatti, G., Womack, R. & Bracco, P., 2006. Incisor intrusion with Invisalign treatment of an adult periodontal patient. *Journal of Clinical Orthodontics* 40, pp. 171–174.
- Vlaskalic, V. & Boyd, R., 2001. Orthodontic treatment of a mildly crowded malocclusion using the Invisalign system. *Australian Orthodontic Journal* 17, pp. 41–46.
- Vlaskalic, V. & Boyd, R., 2002. Clinical evolution of the Invisalign appliance. *Journal of the California Dental Association* 30, pp. 769–776.
- Womack, W., 2006. Four-premolar extraction treatment with Invisalign. *Journal of Clinical Orthodontics* 40, pp. 493–500.
- Womack, W. & Day, R., 2008. Surgical-orthodontic treatment using the Invisalign system. *Journal of Clinical Orthodontics* 42, pp. 237–245.

12

Retention

Simon J. Littlewood¹, BDS, FDS(Orth)RCPS, MDSc, MOrth RCS, FDSRCS, **Declan T. Millett**², BDS, DDS, FDSRCPS, DOrth RCS, MOrth RCS, **David R. Bearn**³, PhD, MSc, BDS, MOrth RCS, FDS(Orth)RCPS, FDSRCS, FHEA, **Bridget Doubleday**⁴, PhD, MDentSci, BDS, MOrth RCS, FDSRCPS, **Helen V. Worthington**⁵, BSc, MSc, PhD

¹Consultant Orthodontist, Orthodontic Department, St. Luke's Hospital, Bradford, UK

²Professor of Orthodontics, Dental School, University College Cork, Cork, Ireland

³Professor of Orthodontics, University of Dundee, Dundee, Scotland, UK

⁴Consultant Orthodontist, Forth Valley Royal Hospital, Stirlingshire, Scotland

⁵Professor of Evidence Based Care, School of Dentistry, The University of Manchester, Manchester, UK

Introduction

Retention is an important part of any orthodontic treatment and is the process by which orthodontists try to minimize relapse following treatment. This chapter will review the causes of relapse and the best contemporary evidence behind attempts to reduce this relapse using retainers and other adjunctive techniques. The section on contemporary evidence is based on the findings of a Cochrane review entitled "Retention Procedures for Stabilizing Tooth Position After Treatment with Orthodontic Braces" (Littlewood et al. 2011), and the reader is directed to the Cochrane Library for the most up-to-date version of this review.

What Is Relapse and What Are the Causes?

Relapse is any change from the final tooth position at the end of treatment. This is often, but not always, movement back toward the original malocclusion. There are broadly four main causes of relapse (Melrose & Millett 1998):

- Periodontal and gingival factors
- Occlusal factors
- Soft tissue pressures
- Growth

Periodontal and Gingival Factors

After tooth movement, the periodontium around teeth needs to remodel. The majority of collagen fibers of the periodontal ligament reorganize on average after 3–4 months. However, elastic fibers around the neck of the teeth, known as the dentogingival and interdental fibers, can take 8 months or longer to reorganize (Reitan 1959). Clinically, this means that teeth have to be held in the corrected position until these fibers have remodeled. This is particularly important when these fibers are stressed, for example after rotational correction. An approach in those cases is to surgically sever the supracrestal fibers using a technique called pericision (see the section titled Pericision, below).

Occlusal Factors

The way the teeth occlude at the end of treatment may also affect the stability of the teeth. Positioning the teeth in the correct occlusal relationship can reduce the relapse in deep bite cases (Houston 1989). It has also been shown retrospectively that the better the quality of the occlusal finish, the less relapse occurs (de Freitas et al. 2007).

Soft Tissue Pressures

The teeth lie in an area of balance between the tongue on one side and the cheeks and lips on the other side (Proffit 1978). This area of balance is sometimes referred to as the *neutral zone*. Although the forces from the tongue are stronger, the activity of a healthy periodontium will resist proclination of the teeth. However, the further the teeth are moved out of this zone of stability, the more unstable they are likely to be.

The problem for the clinician is that it is not possible to visualize the neutral zone, so as a guide it is acknowledged that the bigger the change in the arch form from the start of treatment, the more unstable the treatment is likely to be. This would then need to be taken into account when planning the retention stage of treatment.

Soft tissue pressures are affected by muscle and general soft tissue tone. As these may change with age, the neutral zone and therefore forces on the teeth may alter as the patient gets older.

Growth

While the vast majority of growth is complete by the end of the second decade, it has been suggested that growth may continue, unpredictably, throughout life (Behrents et al. 1989). Subtle changes in the relationship between the maxilla and mandible may exert forces on the teeth later in life, causing changes in tooth position.

Can the Orthodontist Prevent Relapse?

In cases with a healthy periodontium, the orthodontist has the ability to influence the periodontal factors, either by maintaining the teeth long enough for the fibers to remodel or by cutting the supracrestal fibers. The orthodontist can also reduce relapse potential by positioning the teeth in the correct occlusal relationship. Positioning the teeth in the correct relationship with the soft tissues is less predictable, but generally maintenance of the original lower arch form is advisable. The orthodontist may decide to deliberately alter the original lower arch form for improved aesthetics and so increase the likelihood of instability of the final result.

The orthodontist cannot control age changes—this includes soft tissues changes and further growth. At the present time, we are unable to predict the nature of these age changes, so there is the potential for unpredictable relapse throughout life. These late changes may well have little or nothing to do with the orthodontic treatment, but the patient will often attribute the unwanted relapse to it.

Contemporary Approach to Long-Term Relapse

Although some patients will be able to stop wearing retainers without suffering any relapse, it is not possible to identify these patients, and therefore every patient needs to be treated as if he or she has the potential for relapse (Little, Wallen & Riedel 1981). This means there is a need for informed consent before treatment begins, letting patients know about the unpredictable nature of relapse, and the need for some sort of life-long retention to reduce the risk of the relapse. Whether patients choose to wear retainers forever is up to them, but it is important that they are informed of the risk of unpredictable relapse if they choose to discontinue retention.

Retainers

Retainers can be removable or fixed. Removable retainers make oral hygiene easier for patients, and they can be worn part-time if required. Clearly, their success is related to patient compliance. The use of removable retainers means the responsibility for retention is with the patient.

Fixed retainers are bonded in place, usually, but not exclusively, on the lingual surface. They have the advantage that the patient does not need to remember to put them in, and they are particularly useful when the final result is so unstable that anything less than full-time wear would be unacceptable. Examples of situations when bonded retainers are indicated include

1. teeth with periodontally compromised support,
2. malocclusions with initial spacing,
3. following correction of severely rotated teeth, and
4. where the lower labial segment has been significantly moved during treatment

Removable Retainers

The original removable retainer was the Hawley retainer (Figure 12.1). This was originally an active removable appliance that was adapted as a retaining appliance. There are numerous other designs including Begg (wraparound) retainers, Jensen retainers, positioners, spring aligners and vacuum-formed thermoplastic retainers.

Is There an Advisable Daily Retention Regimen for Removable Retainers?

Hawley initially advised wearing his removable retainer for 6 months full-time then part-time thereafter. The idea of wearing a removable retainer full-time for a period before

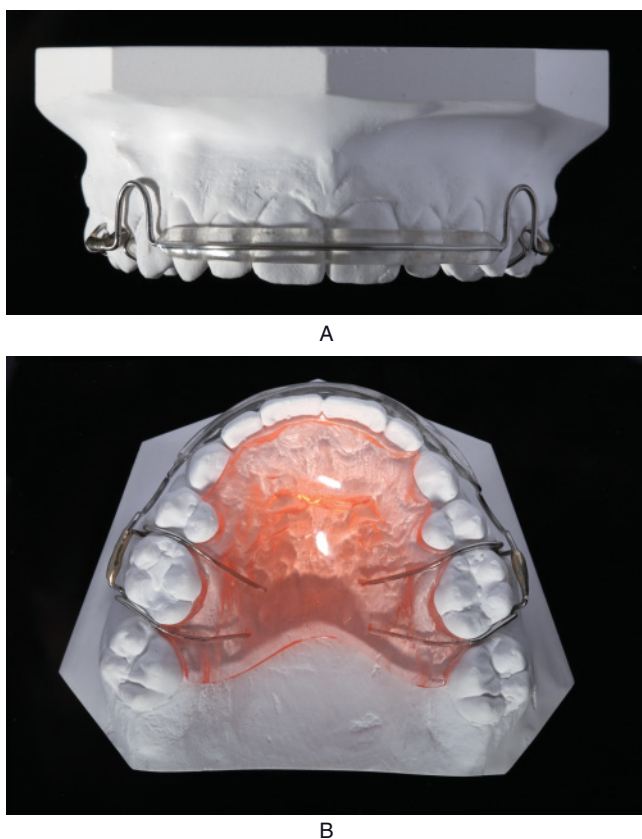


Figure 12.1 Hawley retainer: anterior view (A), occlusal view (B).

reducing to part-time wear has been followed with a variety of removable retainers without any high-quality evidence to support this. Randomized controlled trials have now been completed to determine if full-time wear is necessary (Gill et al. 2007; Thickett & Power 2009; Shawesh et al. 2010). Hawley retainers worn on a part-time basis (at night only) were shown to be equally effective at reducing relapse as Hawley retainers worn full-time for 6 months then nights only thereafter (Shawesh et al. 2010). Similarly, studies comparing vacuum-formed retainers worn on a part-time basis (at night) showed they were as effective as vacuum-formed retainers worn full-time. It appears that in appropriately selected cases, removable retainers need only be worn on a part-time basis from the start of the retention period.

It is important to stress that in these studies patients were excluded if it was felt they needed a permanent bonded retainer for the reasons listed at the beginning of this section.

Which Removable Retainer Is the Most Effective?

It is not possible to definitively answer this question, but following an increase in the use and popularity of vacuum-formed retainers in the UK, a randomized controlled trial was set up to compare vacuum-formed retainers to the traditional Hawley retainer (Rowlands et al. 2007; Hichens et al. 2007). Vacuum-formed retainers (Figure 12.2) were first described in 1971 (Ponitz 1971), and their aesthetic appearance and ease of production has led to their increased popularity, but it was not clear whether this increase in use was appropriate. The clinical trial was set in specialist practice, comparing Hawley retainers to vacuum-formed retainers over the first 6 months of retention. It was shown that patients preferred the vacuum-formed retainer (it was more comfortable and was less embarrassing to wear). The vacuum-formed retainer was also found to be more cost-effective, not only for the orthodontist and the national health system it was provided under but also for the patient. Because it broke less often, the patient did not need to return as frequently to the practice. Finally, although there was no difference in the effectiveness of the retainers in the upper arch, the vacuum-formed retainers were found to be better at preventing relapse in the lower arch.

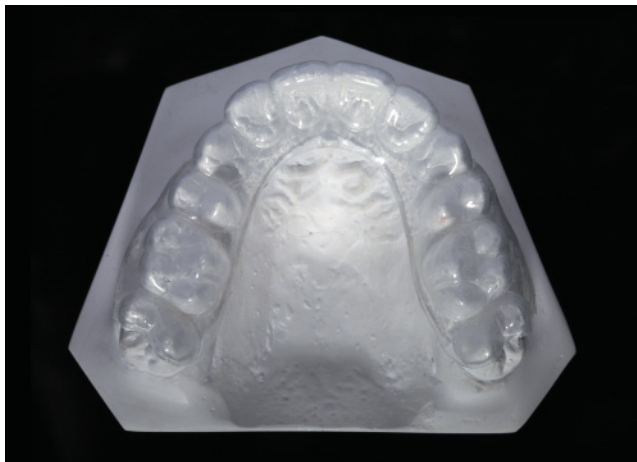


Figure 12.2 Vacuum-formed retainer.



Figure 12.3 Multistrand bonded retainer.

Fixed Retainers

Fixed retainers are bonded to the teeth (Bearn 1995). There are various designs of bonded retainers. They may be made from metal wire (usually stainless steel) or resin-reinforced polyethylene ribbon. Metal retainers may be preformed with small bondable pads or shaped individually for each patient. They may be manufactured from flexible multistrand wire bonded to each tooth in a segment (Figure 12.3) or made from rigid wire and bonded only to selected teeth (e.g., canine-to-canine retainers extend across the lower labial segment but are only bonded to the canine teeth).

Which Type of Bonded Retainer Is Best?

There is insufficient high-quality evidence to confidently state that one type of bonded retainer is better than another type. There is a suggestion that resin-reinforced ribbon retainers are more prone to fracture than multistrand retainers (Rose et al. 2002). The ribbon retainer is made from plasma-treated, polyethylene fibers, which is then reinforced and bonded with composite to the teeth. The composite creates a rigid retainer, and it is possible that the lack of flexibility means the teeth cannot move independently in function, leading to fracture.

One study compared multistrand retainers bonded to the canines and all the incisors in the lower arch with canine-to-canine retainers bonded on only the canines (Stormann & Ehmer 2002). Although the evidence is weak, there is a suggestion that when using canine-to-canine retainers, the incisors (which are not bonded to the retainer) are more prone to relapse. The potential advantage of the canine-to-canine bonded retainers is that if the bond fails on one canine it is obvious to the patient who can then return to have it replaced. This contrasts with multistrand retainers, where individual teeth can debond from the retainer, but by the time the patient realizes the bond has failed, the teeth may have already relapsed.

Bonded Retainers or Vacuum-Formed Retainers?

The use of bonded and vacuum-formed retainers in the lower arch has been compared in one study (McDermott et al. 2007, 2008; Millett et al. 2008). It would seem the patients

preferred the bonded to the vacuum-formed retainers because they found them more acceptable to wear. However, the clinicians preferred the vacuum-formed retainers, as they were easier to fit. One of the common disadvantages described for bonded retainers is that they break, leading to relapse. Although some bonded retainers did break in this study, overall more vacuum-formed retainers cracked or were lost. As a result, more incisor irregularity recurred with the patients wearing vacuum-formed retainers. In terms of dental and periodontal health, there was slightly more gingival inflammation and periodontal pockets (>3 mm) with the patients wearing the bonded retainers, but for neither group did any caries occur. The long-term clinical significance for this is unclear. Certainly, however, it would seem that good initial care instructions are important for bonded retainer patients, and the need for long-term maintenance may be important.

Adjunctive Techniques to Reduce Relapse

Adjunctive techniques involving hard and soft tissue alterations have been used to enhance stability: interproximal enamel reduction and pericision of gingival fibers.

Interproximal Reduction

It has been suggested that interproximal reduction (Figure 12.4) of lower incisors may contribute to increased stability by reducing the amount of excess tooth tissue (Aasen & Espenland 2005) or perhaps by providing a more stable interdental contact. When comparing patients who were fitted with a rigid canine-to-canine retainer in the lower arch with patients who had interproximal reduction but no retainer, no difference was demonstrated in the amount of relapse after 1 year (Edman Tynelius, Bondemark & Lilja-Karlander 2010). It would seem that, at least in the short-term, interproximal reduction may have a role to play in malocclusions without any underlying skeletal anomaly.



Figure 12.4 Interproximal reduction.

Pericision

Pericision, also known as *circumferential supracrestal fiberotomy*, is the process of cutting the interdental and dentogingival fibers around the cervical region of the tooth. The quality of evidence is much lower for this approach, but two nonrandomized, prospective controlled clinical studies suggest that the technique may be successful in reducing the relapse of rotated teeth (Edwards 1988; Taner et al. 2000). These studies are not included in the most recent Cochrane review because they did not fulfill the inclusion criteria of randomized controlled clinical trials. However, they were included here for completeness, as currently providing the best available evidence for this approach. Pericision may reduce the amount of rotational relapse by up to 30%, with no adverse effects on the health of the periodontal ligament.

Conclusions

Relapse is an unpredictable risk factor for every patient. Before treatment begins, patients need to be informed of the long-term risk of relapse and the ways that this may be reduced.

Some causes of relapse are within the control of the orthodontist. Others, such as soft tissue changes and latent growth, are not, and may explain long-term changes in tooth position.

Removable retainers offer the potential for better oral hygiene, and patients are responsible for their wear. At least in the short-term, vacuum-formed retainers may be preferable to Hawley retainers as they are more cost-effective, preferred by patients, and more effective at reducing relapse in the lower arch. Vacuum-formed retainers or Hawley retainers can be worn on a part-time basis and do not require a period of full-time wear.

Bonded retainers may offer advantages over vacuum-formed retainers, as patients prefer them and they provide better retention. This is because although bonded retainers can break, vacuum-formed retainers are lost more frequently and therefore are not worn. Bonded retainers have the disadvantage of needing long-term maintenance to ensure that they are not compromising periodontal health and are still firmly bonded.

Interproximal reduction may have a role in reducing relapse in the lower labial segment, and pericision may reduce rotational relapse. Further high-quality clinical trials would resolve some of the uncertainties in post-treatment relapse and retention protocols.

References

- Aasen, T.O. & Espeland, L., 2005. An approach to maintain orthodontic alignment of lower incisors without the use of retainers. *European Journal of Orthodontics* 27, pp. 209–214.
- Bearn, D.R., 1995. Bonded orthodontic retainers: a review. *American Journal Orthodontics and Dentofacial Orthopedics* 108, pp. 207–213.
- Behrents, R.G., Harris, E.F., Vaden, J.L. et al., 1989. Relapse of orthodontic treatment results: growth as an etiologic factor. *Journal of the Charles H. Tweed International Foundation* 17, pp. 65–80.
- Edman Tynelius, G., Bondemark, L. & Lilja-Karlander, E., 2010. Evaluation of orthodontic retention capacity after one year of retention—a randomized controlled trial. *European Journal of Orthodontics*, DOI 10.1093/ejo/cjp145.

- Edwards, J.G., 1988. A long-term prospective evaluation of the circumferential supracrestal fiberotomy in alleviating orthodontic relapse. *American Journal of Orthodontics and Dentofacial Orthopedics* 93, pp. 380–387.
- de Freitas, K.M.S., Janson, G., de Freitas, M.R. et al., 2007. Influence of the quality of the finished occlusion on postretention occlusal relapse. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 428.e9–428.e14.
- Gill, D.S., Naini, F.B., Jones, A. et al., 2007. Part-time versus full-time retainer wear following fixed appliance therapy: a randomized prospective controlled trial. *World Journal of Orthodontics* 8, pp. 300–306.
- Hichens, L., Rowland, H., Williams, A. et al., 2007. Cost-effectiveness and patient satisfaction: Hawley and vacuum-formed retainers. *European Journal of Orthodontics* 29, pp. 372–378.
- Houston, W.J., 1989. Incisor edge-centroid relationships and overbite depth. *European Journal of Orthodontics* 11, pp. 139–143.
- Little, R.M., Wallen, T.R. & Riedel, R.A., 1981. Stability and relapse of mandibular anterior alignment-first premolar extraction cases treated by traditional edgewise orthodontics. *American Journal of Orthodontics* 80, pp. 349–365.
- Littlewood, S.J., Millett, D.T., Doubleday, B. et al., 2011. Retention procedures for stabilising tooth position after treatment with orthodontic braces. *Cochrane Database of Systematic Reviews*. In press. See www.cochrane.org.
- McDermott, P., Field, D., Erfida, I. et al., 2007. Operator and patient experiences with fixed or vacuum formed retainers. In: *Irish Division IADR Conference Abstract 0017. Journal of Dental Research*, 87, Special Issue B. 2008 IADR/CADR 86th General Session, Toronto, Ontario, Canada.
- McDermott, P., Millett, D.T., Field, D. et al., 2008. Lower incisor retention with fixed or vacuum formed retainers. In: *IADR Conference Abstract 0642. Journal of Dental Research*, 87, Special Issue B. 2008 IADR/CADR 86th General Session, Toronto, Ontario, Canada.
- Melrose, C. & Millett, D.T., 1998. Toward perspective on orthodontic retention? *American Journal of Orthodontics and Dentofacial Orthopedics* 113, pp. 507–514.
- Millett, D.T., McDermott, P., Field, D. et al., 2008. Dental and periodontal health with bonded or vacuum-formed retainer. In: *IADR Conference Abstract 3168. Journal of Dental Research*, 87, Special Issue B. 2008 IADR/CADR 86th General Session, Toronto, Ontario, Canada.
- Ponitz, R.J., 1971. Invisible retainers. *American Journal of Orthodontics* 59, pp. 266–272.
- Proffit, W.R., 1978. Equilibrium theory revisited: factors influencing position of the teeth. *The Angle Orthodontist* 48, pp. 175–186.
- Reitan, K., 1959. Tissue rearrangement during the retention of orthodontically rotated teeth. *The Angle Orthodontist* 29, pp. 105–113.
- Rose, E., Frucht, S., & Jonas, I.E., 2002. Clinical comparison of a multistranded wire and a direct-bonded polyethylene ribbon-reinforced resin composite used for lingual retention. *Quintessence International* 8, pp. 579–583.
- Rowland, H., Hichens, L., Williams, A. et al., 2007. The effectiveness of Hawley and vacuum-formed retainers: a single-center randomized controlled trial. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 730–737.
- Shawesh, M., Bhatti, B., Usmani, T. et al., 2010. Hawley retainers full or part time? A randomized clinical trial. *European Journal of Orthodontics*, DOI 10.1093/ejo/cjp082.
- Stormann, I., Ehmer, U., 2002. A prospective randomized study of different retainer types. *Journal of Orofacial Orthopedics* 63, pp. 42–50.
- Taner, T., Haydar, B., Kavuklu, I. et al., 2000. Short-term effects of fiberotomy on relapse of anterior crowding. *American Journal of Orthodontics and Dentofacial Orthopedics* 118, pp. 617–623.
- Thickett, E. & Power, S., 2009. A randomized clinical trial of thermoplastic retainer wear. *European Journal of Orthodontics*, DOI 10.1093/ejo/cjp061.

Quality of Outcome

Stephen Richmond¹, BDS, DOrth RCS, MScD, FDSRCS, PhD, FHEA, **Alexei Zhurov²**, PhD

¹Professor of Orthodontics, Dental School, University Dental Hospital of Wales, Cardiff, UK

²Research Officer, Dental School, Cardiff University, Cardiff, UK

It is important to quantify change and the outcome of a clinical intervention to determine how effective the intervention process is. Clinicians should be able to measure change at any stage of treatment for a single patient or groups of patients, and the change recorded can be related to the facial and occlusal status at the previous visit or the start of treatment. The differences at each stage of treatment can be judged against a known predicted outcome, best available evidence, or consensus agreement obtained from a panel of professionals and/or laypersons. The assessment of the outcome of treatment can incorporate additional constraints such as perceived benefits, timing, duration, cost, and adverse effects.

The assessment of outcome is complicated by the long duration of most interventions, and these interventions are often undertaken at a time when significant facial growth is observed. Therefore, when assessing the effectiveness of an intervention, the outcome has to quantify the effect of the intervention over and above the predicted or observed growth and developmental changes.

This chapter will provide a brief overview on a range of health technology assessments for determining orthodontic outcomes with regard to

- facial morphology,
- alignment and fit of teeth,
- cost-effectiveness,

- perceived benefits of orthodontic treatment: facial and dental attractiveness, socio-psychological factors, and
- patient satisfaction

Facial Morphology

Facial structures have been captured radiographically for over 70 years, and the plethora of cephalometric analyses suggest that these assessments do not necessarily capture the detail clinicians seek and lack the sensitivity in discriminating the effects of facial growth and orthodontic intervention. Initially, the standardization of image capture was thought to be assured with the patient held in a fixed position with the head aligned to the Frankfurt plane. However, research into positioning errors suggests that the variants on natural head posture may show greater consistency compared with the fixed location using nasal and external auditory meatus positioners (Barbera, Sampson & Townsend 2009; Cuccia & Caradonna 2009). Cephalometric analyses use various facial landmarks as a reference to identify a feature of the anatomy. These facial landmarks fall into four main categories (1) the center of a structure or space (e.g., Sella); (2) juxtaposition (e.g., Nasion); (3) deepest concavity/convexity (e.g., A and B points); and (4) extreme point—most anterior/posterior/superior/inferior (e.g., anterior nasal spine/posterior nasal spine). There will be significant spatial differences in landmark positioning depending on how the cephalogram is aligned. If the cephalogram is aligned on the Sella-Nasion line, with the Sella as origin, superimposition of sequential radiographs will project the face downward and forward similar to that observed during normal growth. However, superimposition at Nasion would show an inferior and posterior growth rotation. The superimposition on the Sella-Nasion line at Sella is commonly used, although it should be acknowledged that the downward and forward movement may be overestimated due to remodeling of the posterior clinoid process and forward development of Nasion anteriorly and superiorly during the ages of 8 to 18 years.

The reliability in locating landmarks also varies accordingly to the clarity and definition of each landmark as well as male and female characteristics (Gwilliam, Cunningham, & Hutton 2008; Toma et al. 2009). In both 2-D and 3-D growth studies, males exhibit greater changes in facial height and width, with significant increased prominence of the glabella, Nasion, pogonion, and pronasale (Kau & Richmond 2008). It would be ideal to register and compare all facial landmark data on a common reference framework. The use of the Sella-Nasion plane at Sella would not be suitable because, as mentioned previously, the landmarks move as a result of normal developmental growth. Another technique has been proposed, such as Procrustes analyses (Bookstein 1991; McIntyre & Mossey 2003, Bruner & Manzi 2004). Procrustes analyses places all recorded landmarks from two faces into one configuration to highlight changes in the landmarks as a result of growth or clinical intervention. Generalized Procrustes superimposition uses a groupwise method of registration for many faces. The process seeks the best fit of all landmarks relative to the centroid, which may not relate to an anatomical structure that moves least. Therefore, changes will be seen relative to an arbitrary point (centroid) as opposed to a defined structure.

The 3-D imaging capture techniques such as soft tissue surface scanning, cone beam computerized tomography (CBCT), and magnetic resonance imaging (MRI) have the potential to overcome some of the drawbacks of 2-D landmark and structure registration (Richmond, Toma & Zhurov 2009, Kau & Richmond 2010). The techniques of 3-D radio-

graphic imaging techniques are often restricted to major craniofacial anomalies due to the risks associated with radiation exposure. However, magnetic resonance imaging is noninvasive and may be seen as an alternative approach to the capture of anatomical structures. It has been used to assess dimensional vector changes in test and control groups based on 3-D registration on skeletal structures (Cevitanes et al. 2005a, 2005b). However, the size of the apparatus, duration of MRI image capture, and its expense is likely to restrict its use.

The face is categorized according to the horizontal, vertical, and transverse planes defining the face as long, average, short and wide, and average and narrow. Although these are useful overall classifications, they do not incorporate the detail of other facial features such as chin, lips, cheeks, nose, and eyes. In an era of determining a biological basis for morphological features, it is possible to determine genotype-phenotype relationships through genomewide association studies (Allanson et al. 2009; Hall et al. 2009; Hennekam et al. 2009). These studies have been useful in identifying genes associated with cleft lip (Grant et al. 2009), and there are several studies in progress to identify genes that may influence specific facial features.

There has been considerable advancement in evaluating change in facial landmarks using 3-D imaging, and this provides the opportunity in classifying and characterizing detailed facial morphology. The surface detail captured using laser or photogrammetric methods are far superior to that obtained from photographs and radiographic methods in terms of dimensional accuracy and surface image resolution. As in any assessment of change or comparison, the superimposition of sequential facial images is challenging; however, the general principles should be adhered to, that is, alignment on reproducible planes and center on landmarks and structures that move least.

Twenty-one landmarks are shown (Figure 13.1). These landmarks can be used for groupwise Procrustes registration, and if needed certain landmarks can be weighted accordingly to reflect structures that move least. The variation for 21 landmarks for a sample of 350 children aged 15 years is shown using ellipsoids (Figure 13.2). Each ellipsoid represents 2 standard deviations from the mean (95% of the variation). The yellow ellipsoids represent unscaled data and green the scaled data. The scaled data eliminates

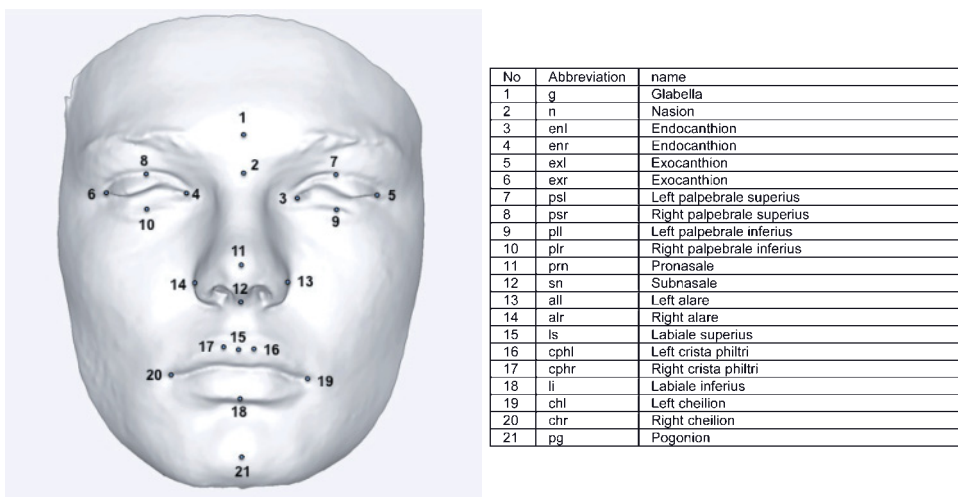


Figure 13.1 Twenty-one facial landmarks identified to assess change.

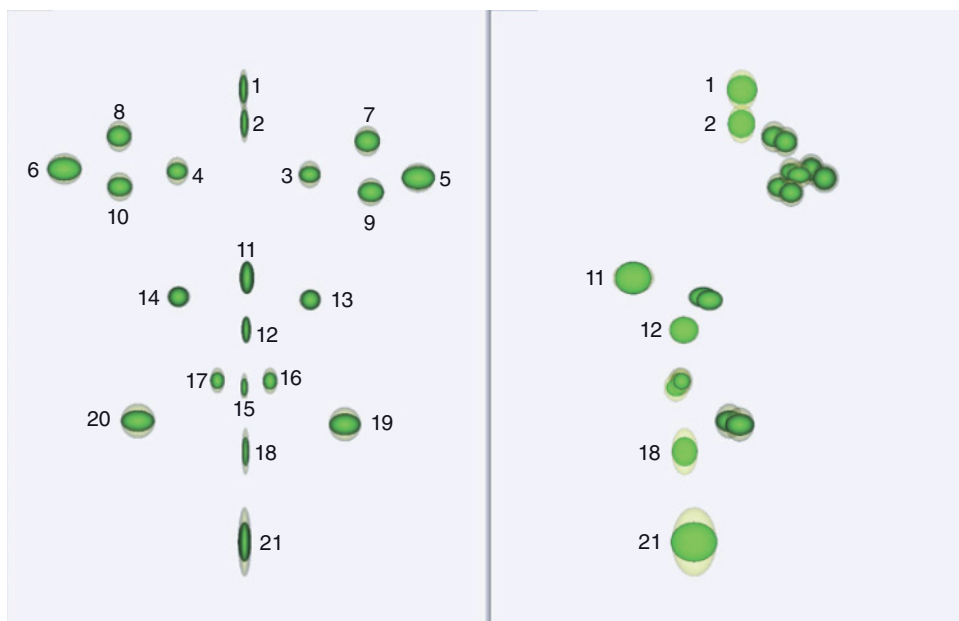


Figure 13.2 The variation of 21 facial landmarks for 350 fifteen-year-old boys and girls. Yellow ellipsoids represent unscaled and green ellipsoids scaled facial landmarks. The data was aligned on the landmarks centroid.

size, and as a consequence the degree of variation is considerably reduced, particularly in the vertical dimension for landmarks pogonion (21), labiale inferius (18), Nasion and glabella (1) (Richmond, Toma & Zhurov 2009, Kau & Richmond 2010). Assessing both size and shape may be of use in scrutinizing the change resulting from growth and clinical interventions.

The change in the 21 facial landmarks in a cohort of Cardiff children was followed from the age of 12 to 16 years of age (23 females and 26 males). The data was scaled and aligned to the respective planes, the origin being the mid-intercanthal point (this point moves least during the growth period) (Figure 13.3). To differentiate between males and females and age groups the ellipsoids have been assigned different colors. For the female facial landmarks, the front and profile views at 12 years old are shown in red and at 16 years of age, yellow. For the male facial landmarks, the front and profile views at 12 years old are shown in green and at 16 years old, blue. The combined superimposition highlights the relative change in landmarks for sex and ages (based on the mid-intercanthal point as the origin). There is greater variability in the pogonion, surprisingly more so in girls compared to boys at both 12 and 16 years of age. There is an increase in forward projection, width, and height in the male face compared to the female face at both 12 and 16 years of age.

There is greater downward and forward growth in males compared to females. This illustration of sex differences between males and females suggests that male and female data should be assessed separately. Any claims of an effect of an intervention compared with a control group should demonstrate statistically significant differences from normal variation.

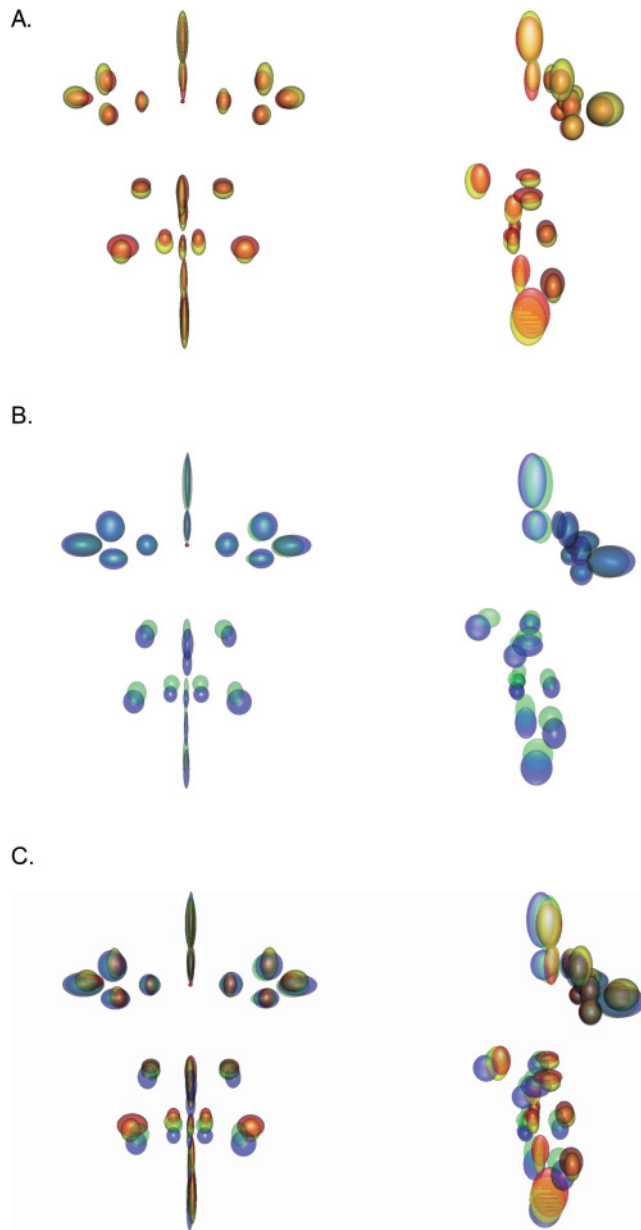


Figure 13.3 Variation in facial landmarks for a cohort of 23 girls and 26 males 12 and 16 years of age. The small red dot indicates the mid-endocanthion point. Courtesy of Cardiff University. (A) Female facial landmarks (front and profile view 12 years old, red; 16 years old, yellow). (B) Male facial landmarks (front and profile view 12 years old, green; 16 years old, blue). (C) Female and male facial landmarks for 12 and 16 years of age superimposed on a standardized 3-D coordinate system.

So far we have seen the variation in 21 landmarks, and the face exhibits a wide variation in facial morphology; and most 3-D imaging systems capture at least 40,000 points on the facial surface, and facial topography may be more meaningful in terms of facial appearance. We have already seen the benefits of scaling using landmarks, but the importance is emphasized using the whole face. Any group studied will show variation. Acknowledging and managing this variation is important. In a sample of 20 children aged 7 years, there is considerable facial variation highlighted by the facial shells at the extremes (Figure 13.4). When the facial extremes are aligned, the lower lip of the shorter face

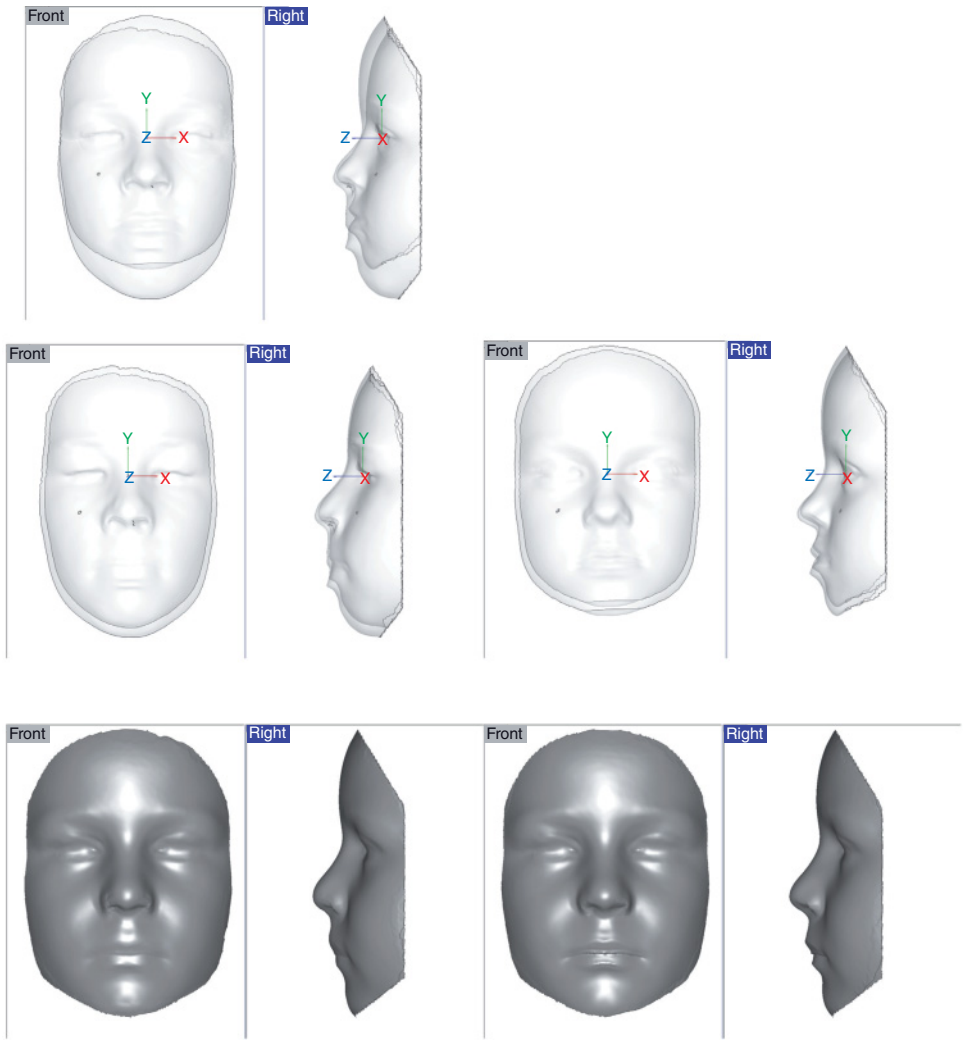


Figure 13.4 The different face sizes in a sample of 20 male children will affect the average facial shape derived (bottom left). Scaling the face will preserve the spatial morphological features resulting in a better representation of the average male face for a 7-year-old child (bottom right).

coincides with the upper lip of the upper face. To reduce this effect of “misalignment” of facial features the faces should be scaled to the mean: the long face scaled down and the small face scaled up. If this is undertaken for all 20 faces, then a more representative average is created preserving the location and morphology of discrete facial features such as the lips. The resulting scaled average is much sharper (greater representation of morphological features, particularly the lower part of the face) than the unscaled average (Zhurov et al. 2010). These techniques provide a visual display of facial variation that should enhance traditional statistical group comparisons. If all study groups were aligned to a common reference framework, then it would be easier to combine, visualize, and evaluate multicenter studies.

These techniques can be extended to look at groups of individuals. If six male 12-year-old children with differing facial morphologies from the Cardiff cohort are selected and their facial shells are aligned to the mid-sagittal plane, mid-intercanthal point, and average natural head posture at 12 years old, we can see that there is significant facial variation in the middle and lower parts of the faces in both the x - y (frontal) and y - z (mid-sagittal) planes. This variation persists until 17 years of age. The individual facial morphologies remain distinct even though they have increased in size over the 5-year period (Figure 13.5).

The six faces represent different facial morphologies and are of different sizes. It has been reported that similar facial morphologies may grow in a similar way (Richmond, Toma & Zhurov 2009). Four male subjects with similar facial morphologies were identified from the Cardiff cohort study. The facial shells were registered. The facial shells at 16 years of age were superimposed independently of each other on their respective facial shells at 12 years old. The profiles of the faces show similar outlines at 12 and 16 years of age (Figure 13.6). The average faces at 12 and 16 years of age show essentially an increase in lower face height. The facial variation in this group of four children with matched lower facial morphology is considerably less than the six faces shown in Figure 13.5.

The assessment of outcome with regard to the facial surface can be analyzed by superimposing images from two or more sessions and assessing the deviation using color maps. This is best illustrated using a patient prior to and after orthognathic surgery and mapping

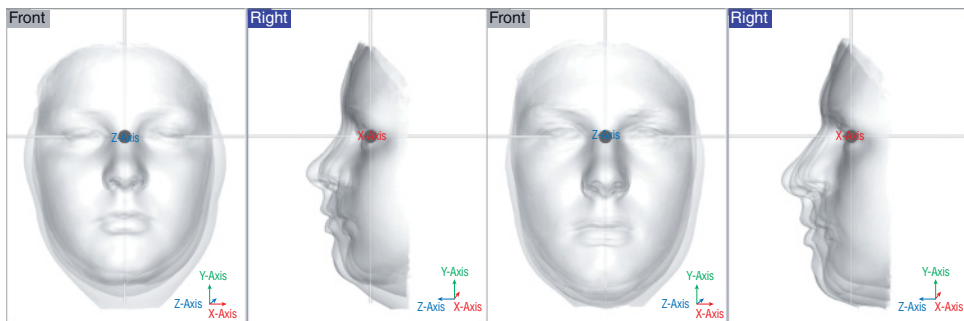


Figure 13.5 Superimposition of six faces on a standardized framework (mid-endocanthion as origin) for the ages of 12 (left) and 17 (right) showing significant facial variation and forward projection of the face.

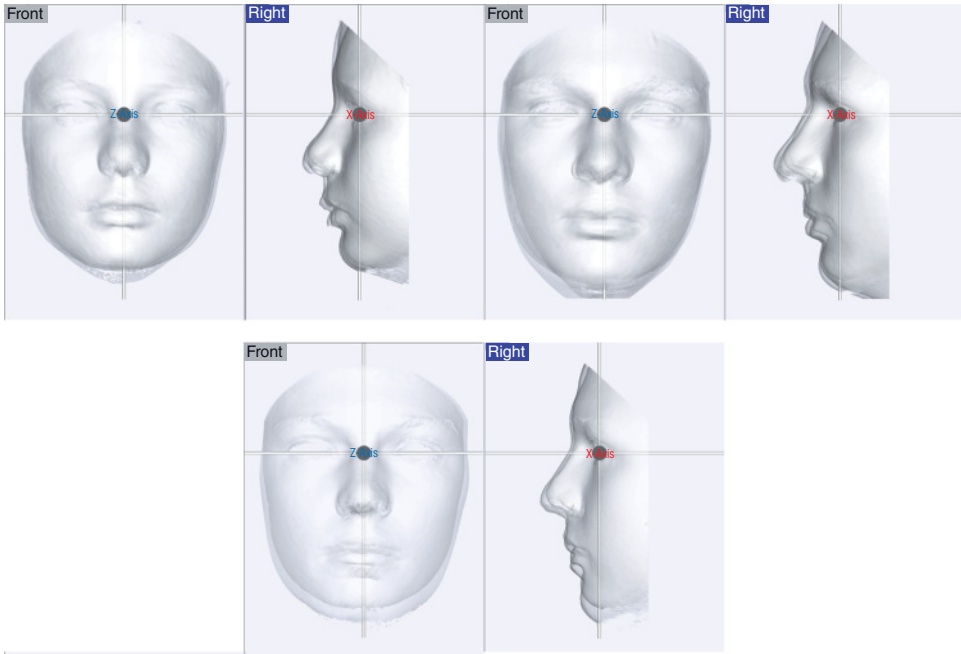


Figure 13.6 Similar growth patterns for similar facial morphologies for four males at ages 12 (top left) and 16 (top right). The average face for the four males at 12 and 16 years of age is shown (bottom).

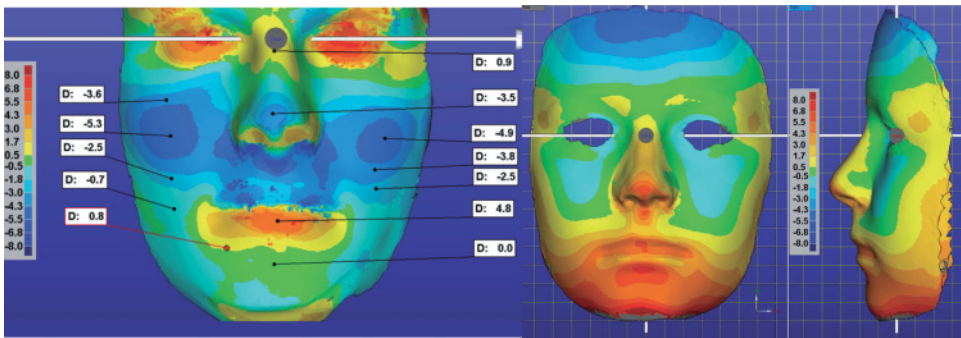


Figure 13.7 The color map shows the changes in the face as a result of a LeFort 1 osteotomy moving the maxilla forward 5 mm (left) and average growth of the face for boys from 12 to 17 years of age (right). The warm colors represent positive changes and the cold colors negative changes. The color scales are shown.

the average growth of the face for boys aged 12 and 17 years of age (Figure 13.7). The color maps provide surface detail of the positive and negative changes.

New 3-D imaging techniques have the opportunity to complement traditional radiographic outcome assessments. Further research is required to monitor growth in large populations to determine growth patterns for specific facial morphological features and dental characteristics based on a standardized reference framework.

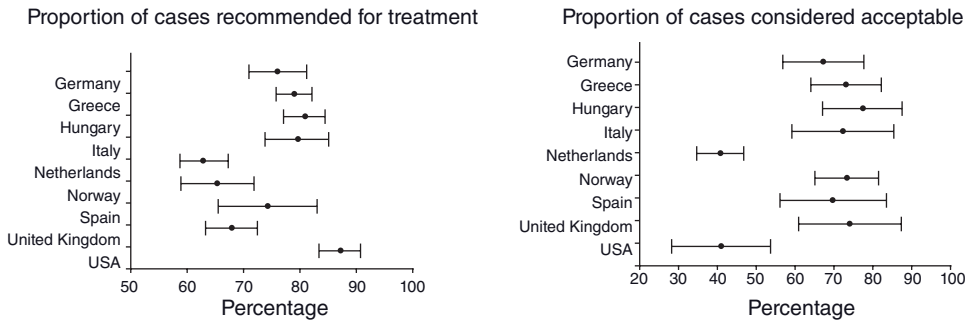


Figure 13.8 Variation of orthodontic practitioners in recommending orthodontic treatment (left) and determining acceptability of the outcome of orthodontic treatment (right).

The Alignment and Fit of Teeth

The simplest method to assess the alignment and fit of teeth would be by visual inspection and evaluating whether a dentition needs treatment or, when treatment has been completed, that the alignment and fit of the teeth is acceptable. Unfortunately, due to the many facets of any orthodontic assessment (e.g., the initial severity and complexity of the alignment and fit of the teeth) and lack of judging criteria, there are significant inconsistencies in the opinions of clinicians in their assessments. Practitioner variation was highlighted in the largest international study undertaken to assess orthodontic treatment need and outcome. To assess treatment need 220 dental casts were judged by 97 orthodontists in nine countries. The proportion of cases that were recommended for treatment ranged from 58% to 92% of the sample (Richmond & Daniels 1998a, 1998b). There was considerable variation not only between countries (58%–92%) but also between orthodontists in the same country (8%–15%). Generally, the least proportion of cases recommended for treatment by orthodontists was in the Netherlands (mean 62%) and the greatest proportion recommended was in the United States (mean 88%). Orthodontists in the United States exhibited the least variation (Figure 13.8).

Surprisingly, even greater variation was seen in the assessment of treatment outcome acceptability where the same 97 orthodontists from nine countries made judgments based on 98 sets of start and finish dental casts. The proportion of casts deemed acceptable ranged from 28% in the United States to 90% in Hungary. There is also considerable variation (15%–30%) within countries. The threshold of acceptability was influenced by the payment/remuneration system; the orthodontists working within the state-controlled payment schemes accepted the highest proportion of cases, followed by private contractors, insurance operators, and least-salaried employees. Interestingly, the more experienced the orthodontist the greater the likelihood that the outcome would be considered acceptable. Inconsistencies in the assessment of orthodontic treatment need and acceptability can affect the credibility of the profession, and it would seem appropriate to ensure uniformity by using internationally accepted objective measures to assess outcome. In addition, a reliable and valid measure of orthodontic treatment need and outcome is essential if researchers wish to evaluate one treatment intervention against another.

The same objective assessment should be employed prior to the start of treatment and at any subsequent occasion, for example during the treatment process, completion of the

Table 13.1 Prerequisites for an objective assessment.

Clinically valid	The extent to which an assessment measures what it is supposed to measure.
Reliable	Concerned with error measurement (random and systematic).
Objective	Resistant to personal idiosyncrasy
Quick, easy, and meaningful	Should not be complex and time-consuming because no one will use it. The intention of assessment must reflect an objective or outcome.
Sensitivity and specificity	Differentiates between various aspects of a measure. The measure should be sensitive to identify and reject issues when they occur or do not occur.
Acceptable to public, profession, and health management organizations	Different specific measures may be of use for different aspects of health care or health care provision. Rarely, one measure satisfies all.
Acceptable and adaptable to cultural norms	Imposing a unified approach for all cultures may not be appropriate, and any objective measure may need adjustment for different population groups.
Adaptable to available resources and expertise	Resources (staff, infrastructure, and funding) within and between communities within and between countries will be different, and adjustment of the measure may be required.

intervention, short-term follow-up (e.g., 1 year), and long-term follow-up (e.g., greater than 5 years) to facilitate an objective assessment.

Before applying any assessment of treatment need/outcome it is important that it follows the appropriate prerequisites (Table 13.1).

There are many occlusal indices available (Table 13.2) that generally categorize and order deviant occlusal traits and the alignment and fit of the teeth (e.g., Peer Assessment Rating (PAR) and Index of Complexity, Outcome and Need (ICON). Some of these dental assessments can be supplemented with facial and cephalometric data (e.g., American Board of Orthodontics Objective Grading Index [ABO-OGS] and Discrepancy Index).

To measure orthodontic treatment outcome on dental casts it is important to make an objective assessment (preferably independently) on pretreatment and posttreatment dental casts. An objective assessment on a completed treatment alone is insufficient and invalid as it is important to identify the change that has taken place. For example, the posttreatment dental cast could be considered acceptable but may be not as good when compared to the pretreatment alignment and fit of the teeth.

Over the last 20 years, the use of objective measures to evaluate treatment need and outcome has become commonplace, with some countries adopting mandatory measures for thresholds for routine orthodontic treatment (e.g., IOTN in the UK and NOTI in Norway); assessment of outcome (PAR in the UK); and for orthodontist accreditation (ABO-OGS in the United States).

Table 13.2 Examples of occlusal indices, type of assessment, and validity.

Index	Assessment Type	Items Recorded	Validity	Reference
ABO-OGS	Outcome	Alignment, marginal ridge, buccolingual inclination, occlusal contacts, occlusal relationship, overjet, interproximal contacts, root angulation (radiographic)	No	Casko et al. 1998
Comprehensive Clinical Assessment	Outcome	Facial aesthetics, dental aesthetics, vertical control, arch form, periodontium management, root structure preservation, and treatment efficiency.	No	Pinskaya et al. 2004
Dental Aesthetic Index	Need	Number of missing visible teeth, crowding in incisal segment, spacing in incisal segment, midline diastema, largest anterior maxillary irregularity, largest anterior mandibular irregularity, anterior maxillary overjet, anterior mandibular overjet, vertical anterior open bite, antero-posterior molar relationship, largest deviation from normal either left or right, constant	Yes	Cons, Jenny & Kohout 1986
Discrepancy Index	Complexity	Overjet, overbite, anterior open bite, lateral open bite, crowding, antero-posterior occlusion, lingual posterior crossbite, buccal posterior crossbite plus 5 cephalometric measures	No	Cangialosi et al. 2004
HLD (cal mod)	Need	12 deviant occlusal traits ordered according to severity	Yes	Draker 1960
ICON	Complexity, need and outcome	10 aesthetic photographs, upper arch crowding/spacing, crossbite, overbite/openbite, antero-posterior occlusion	Yes	Daniels & Richmond 2000
IOTN	Need	Five grades— dental health component, ordered according to severity: 1, no need; 5, very great need	Yes	
NOTI	Need	Four grades—ordered according to severity: very great (A), great (B), obvious (C), and little/no (D) need	No	Espeland, Ivarsson & Stenvik 1992
Occlusal Index	Need	Eleven deviant occlusal scored in a progressive manner	Yes	Summers 1971
PAR Index	Outcome	Crowding, overjet, overbite, posterior occlusion (antero-posterior, vertical, transverse), center line.	Yes	Richmond et al. 1992a, b
Handicapping malocclusion assessment record	Need	Missing, crowding, rotated, spacing, overjet, overbite, open bite, crossbite, posterior occlusion (antero-posterior, vertical, transverse).	No	Salzmann, 1968

An occlusal index is usually developed for a specific purpose (e.g., orthodontic need, complexity, outcome) although one, the Index of Complexity, Outcome and Need, was developed to encapsulate the critical parameters in orthodontic provision (Table 13.2).

There are many different types of occlusal indices that have been reported; however, this chapter will focus on indices that report factors relating to the prerequisites (Table 13.1) and that were subjected to comparison studies (Tables 13.2 and 13.3).

The validity should relate the long-term effect of a specific deviant occlusal anomaly on the dentition and surrounding structures. However, the evidence relating to the deleterious effects of deviant occlusal traits such as increased overjet and crowding is lacking (Chapter 4). Most of the studies use the term *validity* in relation to the association of the progressive index scores with the mean opinions of a group of examiners determined using either visual analog or Likert scales.

To assess reliability the intraclass correlation (ICC) coefficient is often used (Fleiss 1986). The ICC may imply greater reliability than the index warrants; for example, levels of greater than 0.9 are often reported, suggesting almost perfect agreement. The calculation of limits of agreement and assessment of systematic bias may, however, be a more discriminating method (Roberts & Richmond 1997; Brown & Richmond 2005). Both these measures tend to be used in the assessment of reliability of occlusal indices. The reported ICC for the various indices ranges from 0.6 to 0.99 (Table 13.3). The Kappa statistic tends

Table 13.3 Comparison of seven occlusal indices.

		ICON		
	Daniels & Richmond (2000)	Louwerse et al. (2006)	Savastano et al. (2003)	Firestone et al. (2002)
Validity*		0.78		0.81
Reliable		Intra 0.6–0.86 ICC Inter 0.9 ICC	Pre-0.9 ICC Post-0.83 ICC	
Levels of agreement (k)			Complexity-0.52 Outcome-0.50 Improvement-0.27	
Sensitivity	Need-83.6 Outcome-70.1	Need-0.91		Need-91.7
Specificity	Need-85.6 Outcome-64.8	Need-0.84		Need-93.5
Accuracy	Need-84.1 Outcome- 68.1	Need-0.78		Need-92.4
Cut-off	Need-43 Outcome-31	Need-52		Need-52

to produce much lower agreement scores than the ICC and depends on the type used, whether weighted or unweighted (Landis & Koch 1977; O'Connell & Dobson 1984).

Three indices, Dental Aesthetic Index (DAI), Handicapped Labio-Lingual Deviation index (HLD), and the Index of Orthodontic Treatment Need (IOTN), were devised solely to assess orthodontic treatment need, and the Index of Complexity, Outcome and Need (ICON) was constructed to be multipurpose. In terms of treatment need only, high levels of sensitivity, specificity, and accuracy (greater than 82%) for the cutoff levels are reported. Based on these data, the IOTN and ICON would seem the best indices to assess orthodontic treatment need based on orthodontic opinions in the United States, with a cutoff level of grade 3 of the Dental Health Component and 52 ICON points, respectively. A similar study was undertaken in the Netherlands, which reported lower levels of sensitivity and specificity, but these results could be influenced by the lower level of intraexaminer reliability reported in using the index. The original ICON study constructed an index to measure need, complexity, and outcome, and as a consequence the sensitivity and specificity is compromised for the individual assessments because it is mathematically configured to fit all the recorded parameters. Moderate agreement is shown with orthodontists in the United States in relation to complexity and outcome, and fair agreement in relation to improvement. Disagreements between orthodontists are highlighted within and between countries as mentioned previously (Figure 13.6), and it is likely that small groups of orthodontists

DAI	HLD (CalMod)	IOTN DHC AC	DI	ABO-OGS	CCA
Beglin et al. (2001)			Deguchi et al. (2005)		
			0.98	0.97	0.99
Need-92.6	Need-91.7	Need-99.1	Need-84.3		
Need-83.9	Need-82.3	Need-90.3	Need-90.3		
Need-89.4	Need-88.2	Need-91.8	Need-86.5		
Need-28	Need-12	Need-3+	Need-5+		

will generate different opinions and therefore differing mathematical fits with the index data.

The occlusal indices tend to record similar aspects of the occlusion, some in more detail than others. The relationship between seven indices (pre- and posttreatment assessments are shown; Table 13.4). The components of the ICON index were weighted to reflect the opinions of 97 orthodontists from nine countries. There are many published studies replicating the original PAR index study with different weightings, and some studies use unweighted PAR; however, the latter would not have any validity as it does not have any association with orthodontists' opinions. The PAR index here is weighted according to opinions of 74 UK dentists (Richmond et al. 1992a, b).

The correlations between the indices show wide variation, particularly using pretreatment and posttreatment scores. The posttreatment DHC correlates better with the ICON index than the pretreatment score. The aesthetic component of IOTN correlates well with the posttreatment ICON score (0.86) as the 10 dental aesthetic photographs are used in both and this component in ICON will have greater dominance in the posttreatment assessment once all other occlusal anomalies are corrected. The ICON correlates well with the pretreatment PAR score and less so with the posttreatment score. This may be explained by the fact that the ICON tends to be more stringent on the finished case compared to the PAR index (Fox, Daniels & Gilgrass 2002).

It is difficult to recommend a suitable index for assessment as it depends on its purpose. A good generalized index that records many aspects of the alignment and fit of the teeth pre- and posttreatment in a short period of time would be the ICON (Onyeaso & Begole 2007).

Cost-Effectiveness

Assessing the cost-effectiveness of orthodontic care involves considering the effectiveness of care relative to the costs of providing the service. It is unusual to obtain accurate costs of an orthodontic service, as orthodontists are often reluctant to release accurate activity and cost data for commercial reasons. The UK is unique in that activity and costs of the service are routinely recorded to monitor activity and for the practitioners to receive payments. Activity data are viewed differently depending on whether the user of the data is the provider of orthodontic care or a health management organization (HMO) purchasing orthodontic care. The practitioner wishes to maximize profit, and the HMO wants efficiency, with orthodontic care provided for minimal costs. The way the health care system is organized will influence how health care is delivered, and in any system there will be variation within groups of practitioners. The activity profile (representing real data) is outlined for five orthodontists with similar levels of gross income (Figure 13.9; Table 13.5). When the patient has been referred, the orthodontist can accept the patient into treatment, review the patient whose issues may be too early to treat, or refuse treatment because they do not reach the threshold of UK treatment need using IOTN (i.e., DHC 4&5 and DHC 3 and aesthetic component of greater than 5).

The number of patients seen by each orthodontist varies from 428 to 875 patients per year. The proportion of patients accepted for treatment ranged from 212 to 302. Four of the orthodontists (A, B, D, and E) have similar treatment profiles; however, orthodontist C tends to see a greater number of review appointments, resulting in the cost per patient

Table 13.4 Reported correlation coefficients for seven occlusal indices.

	DAI	ICON	OI	PAR	DI	CCA	HMAR	Author
ABO-OGS		0.27				0.59		Onyeaso & Begole 2007 Deguchi et al, 2004
ICON	0.55			0.68*/0.35** 0.51*/0.36**				Onyeaso and Begole 2007 Fox et al. 2002
IOTN			0.31				0.40	Lindauer, Thresher & Baird 1998
AC	0.54	0.64*/0.86**						So & Tang 1993
DHC	0.46	0.17*/0.46**						Shue-Te Yeh et al. (2000)
PAR					0.67*			Deguchi et al. 2004

*Pretreatment.
**Posttreatment.

being quite low and cost per course of treatment being higher compared with other orthodontists. The percentage cost of seeing reviews and/or refusing treatment is relatively small (less than 2%) compared to total gross income. Orthodontists A and D exhibit similarities, as do B and E. For A and D, the number of case starts are greater than the number of reviews, which may be indicative of reduced demand for orthodontic treatment compared to B and C. The number of reviews seems high for practitioner C in relation to the number of cases taken on for treatment and may be indicative of inappropriate referrals. The comparison of these five orthodontists highlights the difficulty in making direct comparisons between orthodontists. Although the five orthodontists have same gross income, it is achieved in slightly different ways as influenced by the supply and demand of patients.

However, the relative efficiency of the throughput of patients provides no information on the effectiveness of orthodontic treatment. The ICON index is ideal to assess the cost-effectiveness of orthodontic treatment as it assesses the pre and posttreatment dental casts and has defined cutoff points for orthodontic treatment need (43 international value) and acceptability (<31 international value).

The effectiveness profiles of two orthodontists are illustrated (Figure 13.10). The *x* axis indicates each case treated, and the vertical axis shows the ICON score. The cases

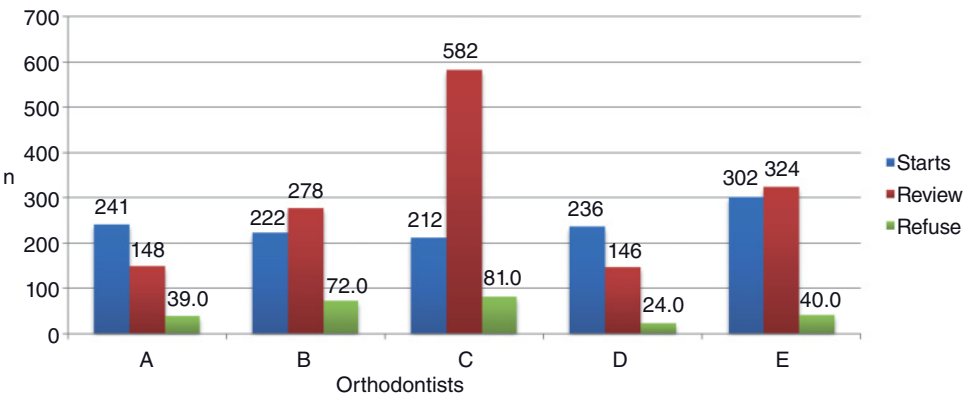


Figure 13.9 Activity data for five orthodontic practitioners.

Table 13.5 Attributed costs to activity data for five orthodontic practitioners.

Orthodontists	Number of patients seen	Number of treatment starts	Number of reviews	% of completed patients of all patients seen	Number of patients refused treatment
A	428	241	187	56	39
B	572	222	350	39	72
C	875	212	663	24	81
D	406	236	170	58	24
E	666	302	364	45	40

have been ordered in increasing severity of occlusion (the more severe cases to the right of the graph). The green line indicates the international treatment need threshold, and the black line the international acceptable outcome threshold. The red columns indicate the initial ICON score, and the yellow columns the ICON score on completion. Orthodontist A treated 40 cases; 8 cases would be considered not needing treatment. One case showed no improvement or was worse (far left yellow bar). Four cases would be considered as having unacceptable finishes. Orthodontist B shows 98 cases. Nine cases would be considered as not requiring treatment, 2 cases indicate that they are no different or worse compared to the start model, and 3 cases would need retreating. Interestingly, the level of severity did not seem to affect the level of outcome. The details of the outcomes are shown, and the cost per ICON point reduction was \$31.8 for orthodontist A and \$27.6 for Orthodontist B. Orthodontist B would be considered more cost-effective than A. The cost-effectiveness of orthodontic care can be determined for any group of orthodontists. Robust league tables can be compiled to highlight the most and least cost-effective orthodontists (Dunstan et al. 2008). These league tables can be used to highlight clinicians providing high-quality care.

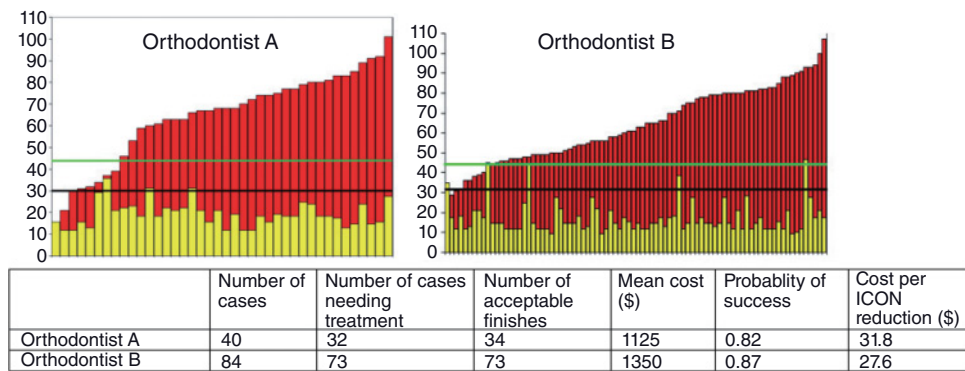


Figure 13.10 The pretreatment (red) and posttreatment (yellow) ICON scores are shown for 40 and 84 cases for orthodontists A and B, respectively.

% of patients refused	Gross income (\$)	Gross costs per patient (\$)	Gross costs per completed treatment (\$)	Costs attributed to reviews	% costs attributed to reviews	% costs attributed to refusal of treatments
9	450,000	1,051	1,867	16,830	4	1
13	450,000	787	2,027	31,500	7	1
9	450,000	514	2,123	59,670	13	2
6	450,000	1,108	1,907	15,300	3	0.5
6	450,000	676	1,490	32,760	7	1

Orthodontists are individuals and as such have different personalities, philosophies, and desires for their patients and themselves, and as a result, practices are often set up and run differently. There are many influences on a practice, such as referring patterns, commercial activities, and third-party health management organizations, all of which have an effect on the uptake and outcome of orthodontic care. The aim of occlusal indices is to ensure that patients presenting with deviant occlusal traits are recognized and referred for treatment to an orthodontist who uses the most cost-effective appliances to achieve the best possible outcome in terms of long-lasting improvement in the alignment and fit of the teeth and, in addition, the improvement in the well-being of the patient.

Perceived Benefits of Orthodontic Treatment: Facial and Dental Attractiveness, Sociopsychological Factors

The stated benefits of orthodontic treatment are improvement in dental aesthetics, dental health, function (masticatory and speech), self-esteem, social and educational development, and quality of life. To support or refute these claims requires a high level of evidence obtained from randomized clinical trials (RCTs) and large-cohort studies with well-documented pretreatment and posttreatment that are followed-up for at least 2 years post-treatment. Not surprisingly, there are very few of these studies available.

Facial Attractiveness

A series of meta-analyses have been published in the last 10 years that have challenged common beliefs that beauty and attractiveness is not important in life (Langlois et al. 2000). Evidence shows that attractiveness influences development and interaction. In a study of 11 meta-analyses, it was concluded that raters agree regarding who is and who is not attractive within and between cultures; attractive children and adults are judged more positively than unattractive children and adults, and attractive children and adults exhibit more positive behaviors and traits than do unattractive children and adults. Physical attractiveness was unrelated to actual intellectual competence in adults but was related modestly in children (Jackson, Hunter & Hodge 1995). The importance of attractiveness later in life was highlighted in earnings. A study of over 700 MBA graduates reported higher starting salaries for males, who continued to earn more over a 10-year period. There was no difference in starting salaries for women. However, more attractive women earned more later on in life (Frieze, Olson & Russell 2006; Pfann et al. 2000; Biddle & Hamermesh 1998; Hamermesh & Biddle 1994).

Several studies have suggested facial attractiveness conforms to mathematical and geometric principles in relation to facial morphology, for example, the golden proportion (1.618 and its reciprocal 0.618), Fibonacci series, averageness, and symmetry (Ricketts 1982; Rhodes 2006). However, the methods employed and the small, convenient samples recruited limit the generalizability of the findings published in the literature (Rhodes 2006). Very few studies have used 3-D data, and there are numerous techniques to obtain an average and symmetrical face that require objective evaluation (Zhurov et al. 2011; Sidorov, Marshall & Richmond 2010).

In a 20-year cohort study, overall facial attractiveness did not appear to depend on any single feature; smiling and youthful facial appearance make women look more attractive; facial attractiveness tends to decrease over time from ages 11 to 31, although people tend to retain their relative levels of attractiveness throughout their life spans. Interestingly, orthodontic treatment improved dental appearance, but it did not necessarily make a person more attractive in the long term. Nevertheless, the authors indicated that orthodontic treatment had a positive effect in males with lower levels of facial attractiveness in childhood (Tatarunaite et al. 2005).

Dental Attractiveness

Overall, dental attractiveness does not appear to depend on any particular feature of the dentition. A hierarchy of various features has been proposed, with crown shape ranked highest and tooth and gum color ranked lowest (Ong, Brown & Richmond 2006). The color of the teeth and gingival display appear to be important in a smile with the teeth being fully displayed and showing 2 to 4 mm of gingiva being judged as an attractive smile (Van der Geld et al. 2007). Caucasians tend to rate black African dental aesthetics as less attractive compared to African judges (Ngom et al. 2005). Females may be more tolerant of gingival exposure than males (Geron & Atalia 2005), and it has been reported that female lip lines tend to be 1.5 mm higher than in males (Peck, Peck & Kataja 1992). The golden proportion/percentage/ratio was not a decisive factor in determining dental attractiveness (Ong, Brown & Richmond 2006; Nikgoo, Alavi & Mirfazaelian 2009). Several studies have been undertaken in which images have been altered to explore discrepancies in upper dental center line in relation to the midline of the face, whereby distances of greater than 2 mm would be deemed less attractive (Beyer & Lindauer 1998; Johnston, Burden & Stevenson 1999) and small or no buccal corridors regarded by laypersons and orthodontists as more attractive than large buccal corridors, although laypersons preferred fewer teeth displayed in a full smile (Martin et al. 2007).

Sociopsychological Factors

Judgments about health are not always clear-cut because individuals usually have a personal stake in the estimation of health and the judgment often depends on the age and timing of when treatment is planned. There may be a tendency for a patient to overestimate a problem if it leads to the intended outcome such as orthodontic treatment and conversely underestimate a problem to avoid treatment. There are instances in which individuals are suffering from life-threatening diseases still wish to undergo orthodontic treatment to satisfy their desire.

A recent systematic review has collated the evidence in respect to malocclusion/orthodontic treatment and the quality of life (Liu et al. 2009). The term *quality of life* is used to evaluate the general well-being of individuals and societies. One hundred and forty-three articles were reviewed, and 23 met the authors' inclusion criteria and employed standardized health-related quality of life (HRQoL) and orthodontic assessment measures. The authors concluded that there was some evidence of an association between malocclusion/orthodontic treatment and quality of life (QoL). There were only two longitudinal studies included that demonstrated a higher level of evidence (Shaw et al. 2007;

O'Brien et al. 2003) and therefore warranted closer inspection. The Class II intention to treat study concluded that if a patient received treatment with a Twin-block appliance, the mean Piers Harris score (a measure for self-esteem) was increased by 4 points in the twin block group ($n = 89$) compared to the control group ($n = 87$).

In the 20-year observational cohort study, 237 individuals out of the original 1,018 recruited attended the recall in 2001 (Shaw et al. 2007). Five psychological health and nine health status QoL measures were employed. There was a significant statistical difference in self-esteem scores (Rosenberg) at 30 years old between those individuals who needed orthodontic treatment in 1981 but did not receive an orthodontic intervention compared with those who needed orthodontic treatment in 1981 and received it ($p < 0.14$). The results indicated that persons with a prior need for orthodontic treatment that was met have a more favorable perception of, and higher satisfaction with, their own teeth than those with an unmet need. However, although initial analysis indicated that these were accompanied by higher levels of self-esteem and reported quality of life, these gains were lost when account was taken of pretreatment self-esteem in 1981. Thus, the results on 31-year-olds confirm those when the cohort was in adolescence: visible malocclusion has no discernable negative effect on social and psychological well-being, and orthodontic treatment has no discernable positive effect. The psychological outcome for the control group in the Class II study could be influenced by the delay in waiting to receive orthodontic treatment.

There is a need for further well-designed studies to explore the relationship between malocclusion/orthodontic treatment and QoL for specific facial and dental morphologies and anomalies.

Patient Satisfaction

Recording patient satisfaction can provide a useful measure of the orthodontic service provided and can explain patients and health-related behavior. The simplest way to assess patient satisfaction is ask the patient whether he or she is satisfied with treatment, and this can be enhanced by documenting the prime reason for their decision. This is a simplistic approach but can highlight aspects of the patients' experience. Patient satisfaction research has been criticized for the lack of reliable and valid instruments, which have undermined the credibility of satisfaction findings (Pascoe 1983; Sitzia 1999). There have been a few studies developing patient satisfaction instruments exploring the treatment process, and clinical and psychological outcomes, and these studies have suggested that patient satisfaction has been associated with reduction in overjet, improved dental aesthetics, patient personality, neurotic scores, oral comfort, and appointment policy (Bennett et al. 2001; Al-Omiri & Abu Alhaija 2006; Njio, ter Heege & Prah-Andersen 2008).

A study of 199 orthodontic patients concluded that patient-perceived orthodontist behaviors are related to and can predict patient-perceived orthodontist-patient relationship, patient satisfaction, and orthodontist-evaluated patient adherence or compliance (Sinha, Nanda & McNeil 1996). The authors highlighted important orthodontist behaviors, such as good communication with patients, politeness, concern about the patient, and showing interest in alleviating anxiety.

Ensuring patient satisfaction in association in the delivery of a high standard of care are prerequisites in building a successful practice and to minimize adverse events that may result in litigation.

Conclusion

New technologies are available to accurately capture facial morphology in three dimensions. New approaches will need to be agreed upon by interested parties to evaluate growth and effectiveness of treatments. The orthodontic profession has an opportunity to prioritize research questions and undertake a systematic approach to determine unequivocal evidence for clinical interventions, and it may be appropriate to revisit and challenge previously entrenched views through scientific rigor and endeavor. We are also at a stage at which the profession should revisit traditional dental and facial classifications with genotype– and phenotype–association studies enabling the creation of new facial categorizations based on biological connections.

Orthodontists have guiding principles and values that create a vision of where they want to be and what they want to achieve for the benefit of themselves, their staff, and their patients. The aspiration of the orthodontist as a team leader sets the ethos in the workplace. Recognition of a good standard of practice is the first goal, but the concept of continuous improvement and honest self-evaluation has a growing universal following and has been introduced to the undergraduate and postgraduate curricula in many institutions worldwide. One of the key areas in developing successful strategies for the delivery of orthodontic care is the establishment of effective communication pathways between the various interested parties. Contributions from all the members of the orthodontist team are important to continually support the theme of improvement so as to encourage empowerment and ownership of a high-quality and successful practice. Many different initiatives have been introduced in different countries to assess quality of orthodontic care. Some of these initiatives have been voluntary, but others have been compulsory. However, if orthodontic quality systems are introduced, they need to be integral to daily working practice.

It is an exciting time to be involved in orthodontics, with new innovations providing researchers with the tools to evaluate both novel and established treatment regimes for the benefit of clinicians and our patients.

References

- Al-Omiri, M.K. & Abu Alhaija, E.S., 2006. Factors affecting patient satisfaction after orthodontic treatment. *The Angle Orthodontist* 76, pp. 422–431.
- Allanson, J.E., Cuniff, C., Hoyne, H.E. et al., 2009. Elements of morphology: standard terminology for the head and face. *American Journal of Medical Genetics. Part A*. 149A, pp. 6–28.
- Barbera, A.L., Sampson, W.J. & Townsend, G.C., 2009. An evaluation of head position and craniofacial reference line variation. *Homo* 60, pp. 1–28.
- Beglin, F.M., Firestone, A.R., Vig, K.W. et al., 2001. A comparison of the reliability and validity of 3 occlusal indexes of orthodontic treatment need. *American Journal of Orthodontics and Dentofacial Orthopedics* 120, pp. 240–246.
- Bennett, M.E., Tulloch, J.F., Vig, K.W. et al., 2001. Measuring orthodontic treatment satisfaction: questionnaire development and preliminary validation. *Journal of Public Health Dentistry* 61, pp. 155–160.
- Beyer, J.W. & Lindauer, S., 1998. Evaluation of dental midline position. *Seminars in Orthodontics* 4, pp. 146–152.

- Biddle, J.E. & Hamermesh, D.S., 1998. Beauty, productivity, and discrimination: lawyers' looks and lucre." *Journal of Labor Economics* 16, pp. 172–201.
- Bookstein, F.L., 1991. *Morphometric tools for landmark data geometry and biology*. Cambridge: Cambridge University Press.
- Brown, R. & Richmond, S., 2005. An update on the analysis of agreement for orthodontic indices. *European Journal of Orthodontics* 27, pp. 286–291.
- Bruner, E. & Manzi, G., 2004. Variability in facial size and shape among North and East African human populations. *The Italian Journal of Zoology* 71, pp. 51–56.
- Cangialosi, T.J., Riolo, M.L., Owens, S.E., Jr. et al., 2004. The ABO discrepancy index: a measure of case complexity. *American Journal of Orthodontics and Dentofacial Orthopedics* 125, pp. 270–278.
- Casko, J.S., Vaden, J.L., Kokich, V.G. et al., 1998. Objective grading system for dental casts and panoramic radiographs. *American Journal of Orthodontics and Dentofacial Orthopedics* 114, pp. 589–599.
- Cevidanes, L.H.S., Bailey, L.J., Tucker, G.R., Jr. et al., 2005a. Superimposition of 3D cone-beam CT models of orthognathic surgery patients. *Dentomaxillofacial Radiology* 34, pp. 369–375.
- Cevidanes, L.H.S., Franco, A.A., Gerig, G. et al., 2005b. Assessment of mandibular growth and response to orthopedic treatment with 3-dimensional magnetic resonance images. *American Journal of Orthodontics and Dentofacial Orthopedics* 128, pp. 16–26.
- Cons, N.C., Jenny, J. & Kohout, F.L., 1986. *DAI: The Dental Aesthetic Index*. Iowa City: College of Dentistry, University of Iowa.
- Cuccia, A.M. & Caradonna, C., 2009. The natural head position. Different techniques of head positioning in the study of craniocervical posture. *Minerva Stomatologica*. 58, pp. 601–612.
- Daniels, C.P. & Richmond, S., 2000. The development of the Index of Complexity, Outcome and Need (ICON). *British Journal of Orthodontics* 27, pp. 149–162.
- Deguchi, T., Honjo, T., Fukunaga, T. et al., 2005. Clinical assessment of orthodontic outcomes with the peer assessment rating, discrepancy index, objective grading system, and comprehensive clinical assessment. *American Journal of Orthodontics and Dentofacial Orthopedics* 127, pp. 434–443.
- Draker, H.L., 1960. Handicapping labio-lingual deviations: a proposed index for public health purposes. *American Journal of Orthodontics and Dentofacial Orthopedics* 46, pp. 295–305.
- Dunstan, F., Richmond, S., Phillips, C. et al., 2008. League tables for orthodontists. *European Journal of Orthodontics* 30, pp. 636–640.
- Espeland, L.V., Ivarsson, K. & Stenvik A., 1992. A new Norwegian index of orthodontic treatment need related to orthodontic concern among 11-year-olds and their parents. *Community Dentistry and Oral Epidemiology* 20, pp. 274–279.
- Fox, N.A., Daniels, C. & Gilgrass, T., 2002. A comparison of the index of complexity outcome and need (ICON) with the peer assessment rating (PAR) and the index of orthodontic treatment need (IOTN). *British Journal of Orthodontics* 193, pp. 225–230.
- Firestone, A.R., Beck, F.M., Beglin, F.M. et al., 2002. Evaluation of the peer assessment rating (PAR) index as an index of orthodontic treatment need. *American Journal of Orthodontics and Dentofacial Orthopedics* 122, pp. 463–469.
- Fleiss, J.L., 1986. *Design and analysis of clinical experiments*. New York: John Wiley & Sons.
- Frieze, I.H., Olson, J.E. & Russell, J., 2006. Attractiveness and income for men and women in management. *Journal of Applied Social Psychology* 21, pp. 1039–1057.
- Geron, S. & Atalia, W., 2005. Influence on the perception of oral and smile esthetics with different gingival display and incisal plane inclination. *The Angle Orthodontist* 75, pp. 778–784.
- Grant, S.F., Wang, K., Zhang, H. et al., 2009. A genome-wide association study identifies a locus for nonsyndromic cleft lip with or without cleft palate on 8q24. *Journal of Pediatrics* 155, pp. 909–913.
- Gwilliam, J.R., Cunningham, S.J. & Hutton, T., 2006. Reproducibility of soft tissue landmarks on three-dimensional facial scans. *European Journal of Orthodontics* 28, pp. 408–415.

- Hall, B.D., Graham, J.M., Cassidy, S.B. et al., 2009. Elements of morphology: standard terminology for the periorbital region. *American Journal of Medical Genetics*. Part A 149A, pp. 29–39.
- Hamermesh, D.S. & Biddle, J.E., 1994. Beauty and the labor market. *American Economic Review* 84, pp. 174–194.
- Hennekam, R.C.M., Cormier-Daire, V., Hall, J. et al., 2009. Elements of morphology: standard terminology for the nose and philtrum. *American Journal of Medical Genetics*. Part A 149A, pp. 61–76.
- Jackson, L.A., Hunter, J.E. & Hodge, C.N., 1995. Physical attractiveness and intellectual competence: a meta-analytic review. *Social Psychology Quarterly* 58, pp. 108–122.
- Johnston, C.D., Burden, D.J. & Stevenson, M.R., 1999. The influence of dental to facial midline discrepancies on dental attractiveness ratings. *European Journal of Orthodontics* 21, pp. 517–522.
- Kau, C.H. & Richmond, S., 2008. Three-dimensional analysis of facial morphology surface changes in untreated children from 12 to 14 years of age. *American Journal of Orthodontics and Dentofacial Orthopedics* 134, pp. 751–760.
- Kau, C.H. & Richmond S., 2010. *Three-Dimensional Imaging for Orthodontics and Maxillofacial Surgery*. Ames, IA: Wiley Blackwell.
- Landis, J.R. & Koch, G.G., 1977. The measurement of observer agreement for categorical data. *Biometrics* 33, pp. 159–174.
- Langlois, J.H., Kalakanis, L., Rubenstein, A.J. et al., 2000. Maxims or myths of beauty? A meta-analytical and theoretical review. *Psychological Bulletin* 126, pp. 390–423.
- Lindauer, S.J., Thresher, A.A. & Baird, B.W., 1998. Orthodontic treatment priority: a comparison of two indices. *Journal of Clinical Pediatrics Dentistry* 22, pp. 125–131.
- Liu, Z., McGrath, C. & Hägg, U., 2009. The impact of malocclusion/orthodontic treatment need on the quality of life. *The Angle Orthodontist* 79(3), pp. 585–591.
- Louwerse, T.J., Aartman, I.H.A., Kramer, G.J.C et al., 2006. The reliability and validity of the Index of Complexity, Outcome and Need for determining treatment need in Dutch orthodontic practice. *European Journal of Orthodontics* 28, pp. 58–64.
- Martin, A.J., Buschang, P.H., Boley, J.C. et al., 2007. The impact of buccal corridors on smile attractiveness. *European Journal of Orthodontics* 29 pp. 530–537.
- McIntyre, G.T. & Mossey, P.A., 2003. Size and shape measurement in contemporary cephalometrics. *European Journal of Orthodontics* 2, pp. 231–242.
- Nikgoo, A., Alavi, K. & Mirfazaalian, A., 2009. Assessment of the golden ration in pleasing smiles. *World Journal of Orthodontics* 10, pp. 224–228.
- Njio, B.J., ter Heege, G.J. & Prah-Andersen, B., 2008. Quality development in a dental practice environment. A web-based system for measuring patient satisfaction. *Journal of Orofacial Orthopedics* 69, pp. 448–462.
- Ngom, P.I., Brown, R., Diagne, F. et al., 2005. A cultural comparison of treatment need. *European Journal of Orthodontics* 27, pp. 597–600.
- O'Brien, K., Wright, J., Conboy, F. et al., 2003. Effectiveness of early orthodontic treatment with the twin-block appliance: a multi-center, randomized, controlled trial. Part 2: psychosocial effects. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 488–494.
- O'Connell, D.L. & Dobson, A.J., 1984. General observer-agreement measures on individual subjects and groups of subjects. *Biometrics* 40, pp. 973–983.
- Ong, E., Brown, R. & Richmond, S., 2006. Peer assessment of dental attractiveness. *American Journal of Orthodontics and Dentofacial Orthopedics* 130, pp. 163–169.
- Onyeaso, C.O. & Begole, E.A., 2007. Relationship between index of complexity, outcome and need, dental aesthetic index, peer assessment rating index, and American Board of Orthodontics objective grading system. *American Journal of Orthodontics and Dentofacial Orthopedics* 131, pp. 248–252.
- Pascoe, G.C., 1983. Patient satisfaction in primary health care: a literature review and analysis. *Evaluation and Program Planning* 6, pp. 185–210.

- Peck, S., Peck, L. & Kataja, M., 1992. Some vertical lineaments of lip position. *American Journal of Orthodontics and Dentofacial Orthopedics* 101, 519–524.
- Pfann, G.A., Biddle, J.E., Hamermesh, D.S. et al., 2000. Business success and businesses' beauty capital. *Economics Letters* 67, pp. 201–207.
- Pinskaya, Y.B., Hsieh, T.J., Roberts, W.E. et al., 2004. Comprehensive clinical evaluation as an outcome assessment for a graduate orthodontic program. *American Journal of Orthodontics and Dentofacial Orthopedics* 126, pp. 533–543.
- Rhodes, G., 2006. The evolutionary psychology of facial beauty. *Annual Review of Clinical Psychology* 57, pp. 199–226.
- Richmond, S. & Daniels, C.P., 1998a. International comparisons of professional assessments in orthodontics: part 1—treatment need. *American Journal of Orthodontics and Dentofacial Orthopedics* 113, pp. 180–185.
- Richmond, S. & Daniels, C.P., 1998b. International comparisons of professional assessments in orthodontics: part 2—treatment outcome. *American Journal of Orthodontics and Dentofacial Orthopedics* 113, pp. 324–328.
- Richmond, S., Shaw, W.C., Roberts, C.T. et al., 1992a. The PAR (Peer Assessment Rating) index: methods to determine outcome of orthodontic treatment in terms of improvement and standards. *European Journal of Orthodontics* 14, pp. 180–187.
- Richmond, S., Shaw, W.C., O'Brien, K.D. et al., 1992b. The development of the PAR (Peer Assessment Rating) index: reliability and validity. *European Journal of Orthodontics* 2, pp. 125–139.
- Richmond, S., Toma, A.M. & Zhurov, A.I., 2009. Nouvelles perspectives sur la croissance cranio-faciale. *L'Orthodontie Française* 80, pp. 359–369.
- Ricketts, R., 1982. The biologic significance of the divine proportion and Fibonacci series. *American Journal of Orthodontics* 81, pp. 351–370.
- Roberts, C.T. & Richmond, S., 1997. The design and analysis of reliability studies for the use of epidemiological and audit indices in orthodontics. *British Journal of Orthodontics* 24, pp. 139–147.
- Salzmann, J.A., 1968. Handicapping malocclusion assessment to establish treatment priority. *American Journal of Orthodontics* 54, pp. 749–765.
- Savastano, N.J., Jr., Firestone, A.R., Beck, F.M. et al., 2003. Validation of the complexity and treatment outcome components of the index of complexity, outcome, and need (ICON). *American Journal of Orthodontics and Dentofacial Orthopedics* 124, pp. 244–248.
- Shaw, W.C., Richmond, S., Kenealy, P.M. et al., 2007. A 20-year cohort study of health gain from orthodontic treatment: psychological outcome. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 146–157.
- Sidorov, K., Marshall, D. & Richmond S. 2010. *Nonrigid image registration using groupwise methods. Three-dimensional imaging for orthodontics and maxillofacial surgery*. Ames, IA: Wiley Blackwell.
- Shue-Te Yeh, M., Koochek, A., Vlaskalic, V. et al., 2000. The relationship of 2 professional occlusal indexes with patients' perceptions of aesthetics, function, speech, and orthodontic treatment need. *American Journal of Orthodontics and Dentofacial Orthopedics* 118, pp. 421–428.
- Sinha, P.K., Nanda, R.S. & McNeil, D.W., 1996. Perceived orthodontist behaviors that predict patient satisfaction, orthodontist-patient relationship, and patient adherence in orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 110, pp. 370–377.
- Sitzia, J., 1999. How valid and reliable are patient satisfaction data? An analysis of 195 studies. *International Journal for Quality in Health Care* 11, pp. 319–328.
- So, L.L.Y. & Tang, E.L.K., 1993. A comparative study using the occlusal index and the index of orthodontic treatment need. *The Angle Orthodontist* 63, pp. 57–64.
- Summers, C.J., 1971. The Occusal Index: a system for identifying and scoring occlusal disorders. *American Journal of Orthodontics* 59, pp. 552–567.

- Tatarunaite, E., Playle, R., Hood, K. et al., 2005. Facial attractiveness: a longitudinal study. *American Journal of Orthodontics and Dentofacial Orthopedics* 127, pp. 676–682.
- Toma, A.M., Zhurov, A., Playle, R. et al., 2009. Reproducibility of facial soft tissue landmarks on 3D laser-scanned facial images. *Orthodontics and Craniofacial Research* 12, pp. 33–42.
- Van der Geld, P., Oosterveld, P., Van Heck, G. et al., 2007. Smile attractiveness. Self-perception and influence of personality. *The Angle Orthodontist* 77, pp. 759–765.
- Zhurov, A.I., Richmond, S., Kau, C.H. et al., 2011. Averaging facial images. In: *Three-Dimensional imaging for orthodontics and maxillofacial surgery*. Kau, C.H. & Richmond, S., editors. Ames, IA: Wiley Blackwell.

Stability of Orthognathic Surgery

Donald R. Joondeph, DDS, MS

Emeritus Associate Professor of Orthodontics, Department of Orthodontics, School of Dentistry, The University of Washington, Seattle, Washington

Anteroposterior Discrepancies

Correction of significant skeletal discrepancies requires either modification of facial growth, dentoalveolar compensation, or orthognathic surgery. Selection and timing of the appropriate treatment alternative is often based upon the extent of the jaw discrepancy in combination with the presence or absence of favorable growth. The plan selected carries with it the expectation by both the clinician and the patient that the final outcome will be a stable, well-functioning occlusion with a favorable aesthetic outcome.

This chapter will focus on the orthognathic procedures commonly used to correct anteroposterior skeletal deformities with particular emphasis on posttreatment stability.

Class II Malocclusion: Mandible Moved Forward with Mandibular Plane Maintained or Rotated Clockwise

Since the primary etiology of the Class II malocclusion is mandibular retrognathia, the most common orthognathic procedures used in the correction is the bilateral sagittal split osteotomy (BSSO) with rigid internal fixation and distraction osteogenesis (DO). Accordingly,

these two procedures will be the focus of this section dealing with the advancement or lengthening of the mandible in the correction of mandibular retrognathia.

Retrospective Studies

Twenty nongrowing subjects who underwent sagittal ramus osteotomies and rigid fixation were examined by Kirkpatrick et al. (1987). Cephalograms were analyzed before, immediately after, and at least 6 months following surgery to evaluate skeletal stability. A mean horizontal relapse of 0.42 mm (8%) and a mean vertical increase in lower face height of 0.2 mm were found 6 months after surgery. Both were statistically insignificant. The mean backward rotation of the mandible of 0.55 degrees found 6 months after surgery was statistically significant but considered to be clinically insignificant. Kirkpatrick and colleagues concluded that surgical mandibular advancement with rigid fixation is a very reliable and stable procedure.

Forty-three patients who underwent surgical lengthening of the mandible using an inverted L osteotomy, bone grafting, and rigid internal fixation between the mandibular segments were evaluated by Barer et al. (1987). This was a retrospective cephalometric analysis for longitudinal skeletal and dental changes. Postoperative response (mean 1 year, 9 months) was found to demonstrate a high level of stability with some individual variation. No propensity for relapse was observed in any postoperative time interval. Condylar repositioning postoperatively appeared to be an important factor in those patients who exhibited any relapse tendency. They stated that overall postoperative stability of this external surgical/fixation technique appeared to be significantly improved compared with previously documented techniques.

Witt (1991) evaluated the long-term stability of intentionally increasing lower anterior face height with mandibular sagittal split osteotomies. During the presurgical orthodontic phase, the mandibular curve of Spee was maintained to ensure the clockwise rotation of the distal segment with maximum increase in facial height during surgery. Lateral cephalometric radiographs were taken and evaluated on 24 adult Class II patients at the following time intervals: before surgery, following surgery, and at a mean of 4 years, 6 months posttreatment. Witt found that a statistically significant increase in lower anterior facial height took place and that this increase in facial height was determined to be statistically stable long term.

A retrospective cephalometric analysis for rotational and linear stability of the proximal and distal segments of the mandible was conducted by Knaup, Wallen & Bloomquist (1993) in 41 patients who underwent bilateral sagittal ramus osteotomy for large mandibular advancements. The patients were grouped by the number of screws used in fixation, three versus four 2-mm bicortical screws, and matched for the amount of advancement measured from changes in mandibular body length. The group with four fixation screws did receive significantly larger advancements relative to the cranial base than did the group with three screws. However, the pattern of postoperative change was similar for the two groups. There was no higher rate of relapse seen in those patients with high mandibular plane angles, genioplasties, mandibular constriction with symphyseal osteotomy, or open bites preoperatively, nor did the number of screws used in fixation affect changes seen in those patients.

Bailey, Cevidanes & Proffit (2004) evaluated data from the University of North Carolina Dentofacial Program containing over 1,400 patients with at least 1 year posttreat-

ment follow-up. They found that mandibular advancement in patients with short or normal face height and less than 10 mm of advancement is one of the two most stable orthognathic procedures, along with superior repositioning of the maxilla. They stated that both these procedures can be highly stable, defined as more than 90% chance of less than 2-mm change at landmarks and almost no chance of more than 4 mm of change during the first postsurgical year.

A study to identify contributing factors associated with skeletal relapse by analyzing cephalometric changes after bilateral sagittal split osteotomy for advancement was published by Eggensperger et al. (2004). The study included 30 consecutive patients treated with mandibular advancement with a mean age of 23 years. Radiographs taken immediately before surgery, at 1 week, and at 14 months were evaluated. The sample was further divided into hyper- and hypodivergent facial patterns. Measured at B point, skeletal relapse was 1.3 mm (30%) after mean advancement of 4.4 mm. The magnitude of the surgical movement correlated with skeletal relapse. Eggensperger and colleagues found, however, that the correlation was not linear. Advancement of greater than 7 mm was associated with an increased tendency to relapse. The hyperdivergent retrognathic patients had a 30% higher relapse rate, whereas patients with hypodivergent facial patterns showed less relapse.

Prospective Studies

A prospective comparison of skeletal stability following BSSO advancement of the mandible fixed with titanium or biodegradable bicortical screws was published by Ferretti & Reyneke (2002). Forty consecutive patients underwent mandibular advancement, with BSSO performed using a standardized technique. In 20 patients, rigid fixation was achieved by means of titanium bicortical screws; the other 20 patients were fixed with biodegradable copolymer screws made of poly-L-lactic acid (82%) and polyglycolic acid (18%). Lateral cephalograms were obtained 1 week preoperatively, 1 week postoperatively, and after a minimum of 6 months postoperatively. Relevant skeletal points were traced and digitized to evaluate 2-D skeletal change. They found that there was no statistically significant difference in long-term stability between the two groups.

A prospective study was conducted by Borstlap et al. (2004) involving a 2-year follow-up on a group of patients who underwent BSSO for advancement ($n = 222$) of the mandible and who were treated in seven institutions following the same treatment protocol. They found that the mean skeletal relapse at pogonion of the whole group after 2 years was 0.9 mm. They also reported a relationship between the amount of advancement and relapse. The tendency for both horizontal and vertical movement was the same; the larger the surgery effect, the larger the relapse. Finally, they noted that patients with a high mandibular plane angle may be more prone to relapse.

Randomized Trials

Ow and Cheung (2009a) also conducted a randomized controlled trial comparing the skeletal stability of bilateral sagittal split osteotomy (BSSO) and mandibular distraction osteogenesis (DO) for moderate mandibular advancement. Their trial consisted of 14 Class II patients with mandibular hypoplasia requiring mandibular advancement of between 6 and 10 mm. They were randomized into two groups for either BSSO or DO. Serial lateral cephalographs were taken at 2 weeks, 6 weeks, 6 months, and 12 months following surgery

for the assessment of skeletal stability. They found no significant difference in horizontal or vertical skeletal relapse between the two groups at every postoperative time period. They concluded that other patient-related factors need to be considered when selecting techniques.

Reviews

BSSO and DO are the most common techniques currently used to surgically correct mandibular retrognathia. Schreuder et al. (2007) reviewed the literature on these two procedures to determine the differences in response, if any, between them. They stated that some support was found in the literature for DO having advantages over BSSO in the surgical treatment of low and normal mandibular plane angle patients requiring greater than 7 mm of advancement. In all other retrognathic patients, the treatment outcomes of BSSO and DO appeared to be comparable.

A systematic review was done by Joss and Vassalli (2009) to evaluate horizontal relapse and causes in bilateral sagittal split advancement osteotomy with rigid fixation of different types. Twenty-four articles were finally included. Six studies were prospective, and 18 were retrospective. The range of postoperative study records was 6 months to 12.7 years. They found that the short-term relapse for bicortical screws was between 1.5% and 32.7%, for miniplates between 1.5% and 18.0%, and for bioresorbable bicortical screws between 10.4% and 17.4% at point B. The long-term relapse for bicortical screws was between 2.0% and 50.3%, and for miniplates between 1.5% and 8.9% at point B. They concluded the bicortical screws of titanium, stainless steel, or resorbable material show little difference regarding skeletal stability compared to miniplates in the short-term. A greater number of studies with larger skeletal long-term relapse rates were evident in patients treated with bicortical screws instead of miniplates. They also concluded that patients with a low mandibular plane angle have increased vertical relapse, whereas patients with a high mandibular plane angle have more horizontal relapse. Advancements in the range of 6 to 7 mm or more are predisposed to horizontal relapse.

An evidence-based review comparing the skeletal stability and complications of BSSO and mandibular DO in the treatment of mandibular hypoplasia was published by Ow and Cheung (2009b). Based on the articles evaluating stability, patients undergoing BSSO or DO with an advancement or lengthening of between 6 and 10 mm showed similar mean skeletal relapse of 15.0% and 17.1%, respectively, within postoperative months 6 to 12. Greater skeletal relapse was reported for BSSO patients with high mandibular plane angles compared with normal mandibular plane angle patients (29.6% vs. 11.3%). The authors concluded that both BSSO and DO showed similar relapse rates for mandibular advancements between 6 and 10 mm. Both techniques may also share similar risk factors for skeletal relapse.

Summary

The retrospective studies indicate a relapse rate of 8% to 30%. The prospective studies report larger amounts of relapse with larger surgical movements, and one randomized clinical trial reports that DO and BSSO display comparable stability up to 12 months. The review articles also indicate that larger surgical movements display larger amounts of relapse, with some differences in stability between patients with low and high mandibular plane angles. Overall, mandibular advancement that maintains or increases the man-

disbular plane angle (distal segment rotated clockwise) appears to be a relatively stable procedure.

Class II Malocclusion: Mandible Moved Forward with Mandibular Plane Rotated Counterclockwise

Historically, open bite closure through counterclockwise rotation of the mandible and intermaxillary wire fixation was discontinued because of the instability associated with this technique. Correction of open bite deformities with maxillary surgical impaction became the standard of care. Currently, the development of rigid internal fixation has allowed clinicians to again close anterior open bite discrepancies in the mandible using bilateral split osteotomies to autorotate the mandibular distal segment counterclockwise. Closure of an anterior open bite through counterclockwise rotation of the mandible offers several advantages. It might be possible to limit surgery to a single jaw, in this case the mandible, rather than using a bimaxillary procedure. Single-jaw surgery would significantly reduce the cost to the patient, making treatment more affordable. Another major advantage is the elimination of the potentially adverse aesthetic changes associated with maxillary LeFort impaction in patients with certain pretreatment facial characteristics. The jury appears to be “still out” regarding the long-term stability of open bite closure in the mandible, but preliminary data suggest that this procedure is at least as stable as maxillary impaction alone (Joondeph & Bloomquist 2004).

Retrospective Studies

A preliminary report on the stability of bilateral sagittal split osteotomy and rigid internal fixation (Oliveira & Bloomquist 1997) to close anterior open bite malocclusion looked at 10 patients who had completed orthodontics and were at least 1 year out of surgery. They were evaluated cephalometrically at three time periods for dental and skeletal changes. They concluded that although their sample was small, their data suggested that the use of bilateral split osteotomy and 2-mm bicortical screws for the closure of anterior open bite is a relatively stable procedure.

A cephalometric study to compare the skeletal stability and the time course of postoperative changes in high-angle and low-angle Class II patients after mandibular advancement surgery was conducted by Mobarak et al. (2001). Their sample consisted of 61 consecutive mandibular retrognathic subjects who were treated with BSSO and rigid fixation. The patients were divided according to the preoperative mandibular plane angle; the 20 patients with the lowest mandibular plane angle (20.8 degrees $\pm$ 4.9) constituted the low-angle group, and the 20 cases with the highest mandibular plane angle (43.0 degrees $\pm$ 4.0) represented the high-angle group. Lateral cephalograms were taken at six time intervals: immediately before surgery, immediately after surgery, 2 and 6 months after surgery, and 1 and 3 years after surgery. Results demonstrated that the high-angle and low-angle groups had different patterns of surgical and postoperative changes. High-angle patients were associated with both a higher frequency and greater magnitude of horizontal relapse. Although 95% of the total relapse took place during the first 2 months after surgery in the low-angle group, high-angle patients demonstrated a more continuous relapse pattern, with a significant proportion (38%) occurring late in the follow-up period.

Frey et al. (2007) investigated predictors of long- and short-term stability of surgical mandibular advancements with bilateral sagittal split osteotomy. They evaluated 127 Class II patients who received mandibular advancement through BSSO with either rigid internal fixation or wire osteosynthesis. Multiple linear regression analyses were done to assess the association of predictor variables with posttreatment horizontal and vertical B-point movement through 2 years. They found that counterclockwise rotation of the mandibular plane angle was associated with greater horizontal and vertical relapse at all time periods except 8 weeks. Wire osteosynthesis, larger advancements, younger age, and genioplasty were significantly associated with relapse. The authors concluded that surgically closing the mandibular plane angle is associated with late horizontal and vertical relapse, whereas fixation type is related to early B-point movement. Large advancements with forward and upward repositioning of the mandible, genioplasty, and young age also play a role in relapse after BSSO.

Reyneke and Ferretti (2007) suggested that in patients with Class II malocclusion and anterior open bite secondary to a short mandibular ramus and normal condyle, mandibular advancement and counterclockwise rotation is the surgical procedure of choice. The authors believe that individuals who have anterior open bite as a result of short mandibular rami do not have the same facial, skeletal, and occlusal features associated with patients with vertical maxillary excess and open bite. Aesthetic and functional correction in these cases demands a different surgical approach, and consideration should be given to correcting this type of dentofacial deformity by means of mandibular surgery. They state that although there is a paucity of studies in the literature regarding the long-term postoperative stability of rotating the distal segment counterclockwise, skeletal stability after counterclockwise rotation of the mandible as part of the rotation of the maxillomandibular complex was reported by Reyneke et al. (2007) and Chemello, Wolford & Buchang (1994). With this surgical design, an anterior open bite is created by surgical counterclockwise rotation of the maxillary occlusal plane. The counterclockwise rotation of the maxilla is followed by the surgical autorotation of the mandible. Long-term postoperative stability in both studies was found to be comparable to other mandibular surgical procedures.

An investigation to evaluate the stability of correcting anterior open bite malocclusions with bilateral sagittal split osteotomy was carried out by Bisase, Johnson & Stacey (2008). They carried out a retrospective review of adult patients consecutively treated with BSSO and rigid fixation using bicortical positional screws. All 12 patients in their sample presented with a Class I incisal relationship at the completion of surgery, and 10 of the 12 (83%) cases were stable at 1 year. Only 2 of 12 patients presented with an edge-to-edge contact long-term. They state that no complete relapse to an anterior open bite was observed in any of the patients.

The long-term stability of bilateral sagittal split osteotomies with counterclockwise (closing) rotation of the mandible in combination with rigid internal fixation in the correction of anterior open bite deformities was evaluated by Stansbury et al. (2010). They studied 28 patients who had completed orthodontic therapy and had at least 1 year of postoperative follow-up. Of the 28 patients, 12 exhibited some degree of opening rotation (range 1% to 64%, mean 16%), and 16 showed no open bite rotation or continued to experience bite closure. All patients in the study, however, had a positive overbite at 1-year follow-up, suggesting that even though skeletal relapse was observed postoperatively, dental compensation through orthodontic tooth movement resulted in maintenance of the occlusal relationships.

Summary

The literature on counterclockwise rotation to correct Class II open bites consists of retrospective evidence. It suggests that this procedure is stable with rigid fixation.

Class II Malocclusion: Maxilla Up and Mandible Forward

Retrospective Studies

The effect of LeFort I maxillary impaction on the stability of the sagittal split advancement osteotomy was investigated by Ayoub, Stirrups & Moos (1995). They compared the stability of mandibular advancement in two groups of patients: those who had simultaneous LeFort I maxillary impaction and sagittal split advancement osteotomy to those who had only sagittal split advancement osteotomy. Lateral cephalograms taken immediately after surgery, 6 months postoperatively, and at 1 year follow-up were assessed. They found that the magnitude of mandibular relapse was similar in both groups in the form of mandibular clockwise rotation and posterior settling. The mandible rotated by 2.2 degrees in the single-jaw surgery group and 2.5 degrees in the bimaxillary osteotomy group. The mandible settled posteriorly by 1.0 degree in the single-jaw surgery group and 1.2 degrees in the bilateral osteotomy group. The differences were not statistically significant. In all the patients, LeFort I maxillary osteotomy was found to be more stable than was mandibular advancement. They noted that the counterclockwise rotation of the distal mandibular segments and the distraction of the condylar segments during surgery were primarily responsible for mandibular relapse.

Bailey, Phillips & Proffit (2004) stated that rigid internal fixation made a significant difference when both maxilla and mandible are repositioned simultaneously. The combination of maxilla up and mandible forward was considered to be stable, less than a 20% chance of significant posttreatment change and almost no chance of major posttreatment change, only if rigid fixation is used.

A study to retrospectively evaluate the stability of combined LeFort maxillary impaction and mandibular advancement for the correction of skeletal Class II malocclusion was carried out by Arpornmaeklong et al. (2004). They looked at 29 patients, mean age of 22.6 years, who underwent bimaxillary surgery with rigid internal fixation. Cephalometric analyses were performed, and the long-term postsurgical follow-up was a minimum of 12 months, with a mean of 25.2 months. They found no statistically significant movement of the maxilla in either the horizontal or vertical planes. The mean advancement of the mandible was 10.7 $\pm$ 5.6 mm, and in 14 cases the advancement was greater than 10 mm. The authors found that in 34.7% of the patients the mandible relapsed posteriorly between 2 and 4 mm. In the vertical plane, gonion moved superiorly a mean of 2.7 $\pm$ 3.6 mm, which was significant. Significant relapse occurred in 5 female patients with high mandibular plane angles who had undergone large advancements of greater than 10 mm.

A comparison of the long-term skeletal stability following clockwise rotation (CR) and counterclockwise rotation (CCR) of the maxillomandibular complex versus patients treated according to conventional treatment planning principles was conducted by Reyneke et al. (2007). They found that the long-term skeletal stability of the CR group and the CCR group

compared favorably with the conventional treatment group, and all three groups compared well with skeletal stability reported in the literature following double-jaw surgery.

Summary

Simultaneous maxillary and mandibular surgery appears to be relatively stable with rigid fixation. The respective evidence suggests that large movements in subjects with high mandibular plane angles may be more prone to relapse.

Class II Malocclusion: Growth

Issues associated with the management of growing patients with mandibular dentofacial deformities was studied by Wolford, Karras & Mehra (2001) as it presents a unique and challenging problem for orthodontists and surgeons. The surgical procedures required for correction of the deformity may affect postsurgical growth and dentofacial development. In addition, facial growth may continue following surgery and negate the benefits of the surgery performed, resulting in treatment outcomes that are less than ideal. The authors state that from individual patient characteristics, the type of deformity, and the indications for early surgical intervention, it is possible to effectively treat many cases during growth. However, a thorough understanding of facial growth patterns is essential, and each case must be evaluated individually. Finally, surgery is often undertaken with the expectation that additional treatment, including more surgery, may be required after the completion of growth.

In patients with normal rates of maxillary and mandibular growth, the same Class II skeletal and occlusal relationship is maintained throughout growth. The authors suggest that this type of deformity can be surgically corrected during active growth with predictably stable results by using mandibular ramus osteotomies. They state that with healthy temporomandibular joints (TMJs) and proper use of surgical techniques, the rate of growth is essentially unaltered by surgery, and harmonious postoperative maxillary and mandibular growth can be expected with maintenance of the surgical result.

Patients experiencing deficient mandibular growth are initially identified as experiencing progressively worsening mandibular retrusion and Class II malocclusion, as normal maxillary growth outpaces the deficient mandibular growth. If this type of deformity is corrected surgically during growth, a Class II skeletal and occlusal relationship can be expected to recur due to disparate growth of the maxilla and mandible. However, surgery during growth may be indicated in cases with severe deformities that adversely affect function, airway, speech, or psychosocial development. Under these circumstances, the patient and parents must be made aware that additional surgery will likely be necessary when growth is complete.

Class III Malocclusion: Mandible Back

Retrospective Studies

Mandibular setback was listed by Bailey, Cevidane & Proffit (2004) as one of three procedures in the problematic category, along with downward movement of the maxilla and maxillary expansion. Problematic is defined as a 40%–50% chance of 2–4 mm of

postsurgical change and a significant chance of more than 4 mm change. Even with these three procedures, however, they found that at least half of the patients studied experienced essentially no postsurgical change. They stated that every patient does not experience relapse, but rather there is a high chance of relapse.

Eggensperger et al. (2004) investigated the contributing factors associated with skeletal relapse by analyzing cephalometric changes following bilateral sagittal split osteotomy for mandibular setback. There were 30 patients in their sample, with radiographs taken immediately presurgery and at 1 week and 14 months postoperatively. Measured at B point, they found that skeletal relapse was 0.8 mm (12%) after a setback of 6.0 mm. A setback of more than 12 mm was associated with a decreased tendency for relapse, and patients with a hypodivergent facial pattern showed less relapse than those with hyperdivergent characteristics.

Reviews

A systematic review was conducted by Joss and Vassalli (2008) to evaluate relapse and its causes in bilateral sagittal split mandibular setback osteotomy with rigid internal fixation. The range of postoperative study records was from 6 weeks to 12.7 years. The literature suggests that the horizontal short-term relapse was between 9.9% and 62.1% at B point and between 15.7% and 91.3% at pogonion. Long-term relapse was between 14.9% and 28.0% at B point and between 11.5% and 25.4% at pogonion. They concluded from the literature that BSSO for mandibular setback in combination with orthodontics is an effective treatment of skeletal Class III malocclusion and a stable procedure in the short and long term. The authors stated that the etiology of relapse appears to be multifactorial: the proper seating of the condyles, the amount of setback, the soft tissue and muscles, remaining growth and remodeling, and gender were identified as factors. Age did not show any correlations.

Summary

Based on the results of the systematic review, mandibular setback appears to be fairly stable.

Class III Malocclusion: Maxilla Forward

Retrospective Studies

Hoffman and Brennan (2004) studied 45 patients who underwent a one-piece maxillary advancement with elimination of controllable variables, apart from 15 patients who had simultaneous mandibular advancement. Rigid fixation was used throughout the study. The mean surgical maxillary advancement was 7.42 mm whereas the mean stability calculated at 12 months revealed a relapse of 0.72 mm or 10%. This was not statistically significant. The authors concluded that the LeFort advancement osteotomy is a stable and surgically predictable procedure that is associated with only slight relapse at 12 months.

Advancement of the maxilla has been described by Bailey, Cevdanes & Proffit (2004) as falling into their second category as a stable procedure. With forward movement of moderate distances of less than 8 mm, there is an 80% chance of less than 2 mm change,

a 20% chance of 2–4 mm relapse, and almost no chance of more than 4 mm change. However, the authors added an important caveat. Downward movement of the maxilla is in the problematic category; if the maxilla is moved both forward and down, the vertical component is likely to relapse, although the horizontal component has a good chance of being retained.

A retrospective cephalometric study was conducted by Dowling et al. (2005) to assess the amount, direction, and timing of postoperative changes after LeFort I maxillary advancement and to identify risk factors associated with relapse. Their sample consisted of 43 patients who underwent 1-piece LeFort I advancement as an isolated procedure and were subsequently followed for 3 years. Lateral cephalograms were obtained before surgery and at five intervals following surgery. They found that a mean relapse of 18% of the surgical advancement occurred. In 14% of the patients, clinically significant skeletal relapse of ± 2 mm was observed. Most postoperative change (89%) occurred during the first 6 months after surgery. Skeletal relapse increased significantly with degree of surgical advancement and degree of inferior repositioning of the anterior maxilla. At the end of follow-up, overjet and overbite were within clinically accepted ranges for all patients. They concluded that maxillary advancement with a 1-piece LeFort I osteotomy is a relatively stable procedure. Identified risk factors for horizontal relapse were degree of surgical mandibular advancement and degree of inferior repositioning of the anterior maxilla.

Pangrazio-Kulbersh et al. compared the stability of LeFort I maxillary advancement to maxillary palatal expansion with protraction face mask. Their surgical sample comprised 17 adults, 10 men and 7 women. Lateral cephalograms were taken before treatment (T1); 2 weeks postsurgery (T2); and 1 year, 5 months postsurgery (T3). They found that the surgical group remained stable from T2 to T3 in all measurements studied.

Summary

Based on retrospective studies, maxillary advancement appears to exhibit good stability, as long as the maxilla is not moved inferiorly.

Class III Malocclusion: Maxilla Forward and Mandible Back

Retrospective Studies

Kwon et al. (2000) evaluated the 3-D stability of simultaneous maxillary advancement and mandibular setback using rigid fixation. They also attempted to analyze the factors involved in postsurgical relapse by evaluating changes in various parameters in the 25-patient sample. Preoperative, immediate, and 6-month postoperative skeletal and dental changes were analyzed using 3-D cephalograms. Results indicated that the mean maxillary advancement was 3.7 mm and that relapse in the sagittal, vertical, and transverse planes was not detectable in the maxilla. However, for an average mandibular setback of 5.7 mm, mean mandibular relapse was 1.1 mm or 19.3% anteriorly. They concluded that maxillary advancement and vertical changes of ± 2 mm did not influence the postoperative stability

of the mandible. Relapse of the mandible seemed to be influenced mainly by the amount and direction of the surgical alteration of mandibular position.

An evaluation of skeletal stability after double-jaw surgery for correction of skeletal Class III malocclusion was conducted by Politi et al. (2004) to determine if there were any differences between wire and rigid fixation of the mandible. Thirty-seven Class III patients had LeFort I osteotomy stabilized with plate and screws for maxillary advancement. Bilateral split sagittal osteotomy for mandibular setback was stabilized in 20 patients with wire osteosynthesis and maxillomandibular fixation for 6 weeks, whereas 17 patients had rigid internal fixation. Lateral cephalograms were taken before surgery, immediately after surgery, 8 weeks after surgery, and 1 year after surgery. They found that maxillary sagittal stability was excellent in both groups, and the BSSO accounted for most of the total relapse observed. They concluded that the surgical correction of Class III malocclusion after combined maxillary and mandibular procedures appeared to be a fairly stable procedure independent of the type of fixation used to stabilize the mandible.

If rigid fixation techniques are employed, Bailey, Cevidanes & Proffit (2004) listed the simultaneous movement of the maxilla forward and the mandible back as stable with less than a 20% chance of significant posttreatment change and almost no chance of major posttreatment change.

The objective of a study done by Costa et al. (2006) was to evaluate skeletal stability after double-jaw surgery for correction of skeletal Class III malocclusion to assess if there were any differences between resorbable plate and screws and titanium fixation of the maxilla. Their sample consisted of 22 Class III patients who had BSSO for mandibular setback stabilized with rigid internal fixation. Low-level LeFort I osteotomy for maxillary advancement was stabilized with conventional titanium plate and screws in 12 patients, and resorbable plate and screws were used in 10 individuals. Lateral cephalograms were taken before surgery, immediately postoperatively, 8 weeks after surgery, and 1 year postoperatively. They found that 1 year after surgery, maxillary stability was excellent in both groups and that no significant differences in postoperative skeletal and dental stability between groups were observed. The authors concluded that surgical correction of Class III malocclusion after combined maxillary and mandibular procedures appears to be a fairly stable procedure for maxillary advancements up to 5 mm, independent from the type of fixation used to stabilize the maxilla. They also cautioned that resorbable devices should be used with care for bony movements of greater magnitude until their effectiveness is evaluated in studies with large maxillary advancements.

A comparative study evaluating postoperative maxillary stability following LeFort I osteotomy for the correction of occlusal cant as compared with conventional LeFort I osteotomy for maxillary advancement was done by Ueki et al. (2007). The sample consisted of 40 Japanese adults, 20 of whom underwent a LeFort I osteotomy and intraoral vertical ramus osteotomy (IVRO) for the correction of asymmetric skeletal morphology and inclined occlusal cant. The other 20 patients underwent a LeFort I osteotomy and sagittal split ramus osteotomy (SSRO) to advance the maxilla. Lateral and posteroanterior cephalograms were taken postoperatively and assessed statistically, and the two groups were followed for time-course changes. The authors found that there was no significant difference between the two groups with regard to time-course changes during the immediate postoperative period and concluded that maxillary stability after LeFort I osteotomy for cant correction does not differ from that after LeFort I osteotomy for maxillary advancement.

Summary

The retrospective evidence, largely consisting of studies using rigid fixation, indicates that bimaxillary surgery for Class III correction is relatively stable.

Class III Malocclusion: Growth

In a study by Bailey, Phillips & Proffit (2008), the authors assessed whether the likelihood of a positive overjet 5 to 10 years after Class III surgery was affected by age at the surgery or the type of surgery and evaluated the amount and pattern of postsurgical growth. Cephalometric measurements and overjet were evaluated from immediately postsurgery and long-term recall cephalograms of 104 patients who had had surgical Class III correction. The patients were classified as younger (less than 18 years for females at surgery or 20 years for males) or older and by the type of surgery: maxilla only, mandibular only, or two jaw. For the younger patients, the timing of treatment was based largely on serial cephalometric radiographs that eventually showed minimal or no mandibular growth. Long-term changes in overjet and other cephalometric characteristics in the younger and the older patients were similar. No patients in the sample had negative overjet in the long term, but zero overjet (less than 1 mm) was observed in some patients in all groups. Patients who had mandibular setback at any age were 2.6 times more likely to have zero overjet in the long term compared to those with maxillary surgery alone. For the younger patients, the likelihood of zero overjet in the long term was not significantly different from patients who were treated later with or without mandibular surgery. They concluded that their data support the use of serial cephalometric radiographs, with surgery deferred until little or no mandibular growth is observed, to determine the timing of Class III surgery in younger patients.

Use of Condylar Positioning Devices to Improve Surgical Stability

A retrospective study was carried out by Gerressen et al. (2007) to investigate whether use of condylar positioning devices in comparison to the manual positioning technique has a favorable influence on skeletal stability after bilateral sagittal split osteotomy. Lateral cephalometric radiographs of 49 patients who had undergone bilateral sagittal split osteotomy or bimaxillary surgery were evaluated with the aid of analysis software. As a criterion for skeletal stability, the postoperative changes of SNB angle and Wits appraisal were determined. In 10 of 28 patients with mandibular setback, the Luhr positioning device was used intraoperatively to reproduce the condylar position. Mandibular joints of the remaining patients were positioned manually. They found that neither in advancement nor in setback surgery did the positioning device technique result in better outcomes for postoperative changes in SNB angle and Wits appraisal. Their conclusion was that the use of positioning appliances does not lead to improvement of skeletal stability. With the manual technique, equally stable results can be attained in mandibular advancement as well as in setback surgery.

Summary

Although Arnett (1993) has published an excellent summary reviewing the various components he believes to be associated with the relapse seen in the BSSO for mandibular advancement, the causes of surgical relapse appear to be multifactorial and include proper condylar repositioning at the time of surgery, condylar changes following surgery, the technical expertise of the surgeon, type of fixation, the amount and direction of the surgical movement, the facial pattern of the patient, soft tissue and muscular influences, the age of the patient, presence of continued growth, and pre- and postsurgical management by the orthodontist and surgeon. Future studies should prospectively attempt to minimize the impact of as many variables as possible in an attempt to establish criteria for anticipated surgical stability or relapse.

References

- Arnett, W., 1993. A redefinition of bilateral sagittal osteotomy (BSO) advancement relapse. *American Journal of Orthodontics and Dentofacial Orthopedics* 104, pp. 506–515.
- Arpornmaeklong, P., Shand, J. & Heggie, A., 2004. Skeletal stability following maxillary impaction and mandibular advancement. *Oral & Maxillofacial Surgery* 33, pp. 656–663.
- Ayoub, A., Stirrups, D. & Moos, K., 1995. Stability of sagittal split advancement osteotomy: single-versus double-jaw surgery. *International Journal of Adult Orthodontics and Orthognathic Surgery* 10, pp. 181–192.
- Bailey, L., Cevidanes, H. & Proffit, W., 2004. Stability and predictability of orthognathic surgery. *American Journal of Orthodontics and Dentofacial Orthopedics* 126, pp. 273–277.
- Bailey, L., Phillips, C. & Proffit, W., 2008. Long-term outcome of surgical Class III correction as a function of age at surgery. *American Journal of Orthodontics and Dentofacial Orthopedics*, 133, pp. 365–370.
- Barer, P., Wallen, T., McNeill, R. & Reitzik, M., 1987. Stability of mandibular advancement osteotomy using rigid internal fixation. *American Journal of Orthodontics and Dentofacial Orthopedics* 92, pp. 403–411.
- Bisase, B., Johnson, P. & Stacey, M., 2008. Closure of anterior open bite with mandibular orthognathic surgery only. *British Journal of Oral and Maxillofacial Surgery*, 46, pp. e62–e63.
- Borstlap, W., Stoelinga, P., Hoppenreijns, T. & van't Hof, M., 2004. Stabilisation of sagittal split advancement osteotomies with miniplates: a prospective, multicentre study with two-year follow-up: part II. Radiographic parameters. *Oral and Maxillofacial Surgery*, 33, pp. 535–542.
- Chemello, P., Wolford, L. & Buchang, P., 1994. Occlusal plane alteration in orthognathic surgery. Part II: long-term stability of results. *American Journal of Orthodontics and Dentofacial Orthopedics* 104, pp. 434–440.
- Costa, F., Robiony, M., Zorzan, E. et al., 2006. Stability of skeletal Class III malocclusion after combined maxillary and mandibular procedures: titanium versus resorbable plates and screws for maxillary fixation. *Journal of Oral and Maxillofacial Surgery* 64, pp. 642–651.
- Dowling, P., Espeland, L., Sandvik, L. et al., 2005. LeFort I maxillary advancement: 3-year stability and risk factors for relapse. *American Journal of Orthodontics and Dentofacial Orthopedics* 128, pp. 560–567.
- Eggensperger, N., Smolka, W., Rahal, A. & Iizuka, T., 2004. Skeletal relapse after mandibular advancement and setback in single-jaw surgery. *Journal of Oral and Maxillofacial Surgery* 62, pp. 1486–1496.

- Ferretti, C. & Reyneke, J., 2002. Mandibular, sagittal split osteotomies fixed with biodegradable or titanium screws: a prospective, comparative study of postoperative stability. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* 93, pp. 534–537.
- Frey, D., Hatch, J., Van Sickels, J. et al., 2007. Alteration of the mandibular plane during sagittal split advancement: short- and long-term stability. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics* 104, pp. 160–169.
- Gerressen, M., Stockbrink, G., Smeets, R. et al., 2007. Skeletal stability following bilateral sagittal split osteotomy (BSSO) with and without condylar positioning device. *Journal of Oral and Maxillofacial Surgery* 65, pp. 1297–1302.
- Hoffman, G. & Brennan, P.A., 2004. The skeletal stability of one-piece LeFort I osteotomy to advance the maxilla: part 1. Stability resulting from non-bone grafted rigid fixation. *British Journal of Oral and Maxillofacial Surgery* 42, pp. 221–225.
- Joondeph, D. & Bloomquist, D., 2004. Open bite closure with mandibular osteotomy. *American Journal of Orthodontics and Dentofacial Orthopedics* 126, pp. 296–298.
- Joss, C. & Vassalli, I., 2008. Stability after bilateral sagittal split osteotomy setback surgery with rigid internal fixation: a systematic review. *Journal of Oral and Maxillofacial Surgery* 66, pp. 1634–1643.
- Joss, C. & Vassalli, I., 2009. Stability after bilateral sagittal split osteotomy advancement surgery with rigid internal fixation: a systematic review. *Journal of Oral and Maxillofacial Surgery* 67, pp. 301–313.
- Kirkpatrick, T., Woods, M., Swift, J. & Markowitz, N., 1987. Skeletal stability following mandibular advancement and rigid fixation. *Journal of Oral and Maxillofacial Surgery* 44, pp. 572–576.
- Knaup, C., Wallen, T. & Bloomquist, D., 1993. Linear and rotational changes in large mandibular advancements using three or four fixation screws. *International Journal of Adult Orthodontics and Orthognathic Surgery* 8, pp. 245–263.
- Kwon, T-G., Mori, Y., Minami, K. et al., 2000. Stability of simultaneous maxillary and mandibular osteotomy for treatment of Class III malocclusion: an analysis of three-dimensional cephalograms. *Journal of Cranio-Maxillofacial Surgery* 28, pp. 272–277.
- Mobarak, K., Espeland, L., Krogstad, O. & Lyberg, T., 2001. Mandibular advancement surgery in high-angle and low-angle Class II patients: different long-term skeletal responses. *American Journal of Orthodontics and Dentofacial Orthopedics* 119, pp. 368–381.
- Oliveira, J. & Bloomquist, D., 1997. The stability of the use of bilateral sagittal split osteotomy in the closure of anterior open bite. *Internal Journal of Orthodontics and Orthognathic Surgery* 12, pp. 101–108.
- Ow, A. & Cheung, L., 2009a. Bilateral sagittal split osteotomies and mandibular distraction osteogenesis: a randomized controlled trial comparing skeletal stability. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*. Available from: [www.ooooe.net/article/s1079-2104\(09\)00480-6/abstract](http://www.ooooe.net/article/s1079-2104(09)00480-6/abstract) [Accessed December 2009].
- Ow, A. & Cheung, L., 2009b. Skeletal stability and complications of bilateral sagittal split osteotomies and mandibular distraction osteogenesis: an evidence-based review. *Journal of Oral and Maxillofacial Surgery* 67, pp. 2344–2353.
- Pangrazio-Kulbersh, V., Berger, J., Janisse, F. et al. 2007. Long-term stability of Class III treatment: rapid palatal expansion and protraction facemask vs LeFort I maxillary advancement osteotomy. *American Journal of Orthodontics and Dentofacial Orthopedics* 131, pp. 7.e9–7.e19.
- Politi, M., Costa, F., Cian, R. et al., 2004. Stability of skeletal Class III malocclusion after combined maxillary and mandibular procedures: rigid internal fixation versus wire osteosynthesis of the mandible. *Journal of Oral and Maxillofacial Surgery*, 62, pp. 169–181.
- Reyneke, J. & Ferretti, C., 2007. Anterior open bite correction by LeFort I or bilateral sagittal split osteotomy. *Oral and Maxillofacial Surgery Clinics of North America* 19, pp. 321–338.
- Reyneke, J., Bryany, R., Suuronen, R. & Becker, P., 2007. Postoperative skeletal stability following clockwise and counter-clockwise rotation of the maxillomandibular complex compared to con-

- ventional orthognathic treatment. *British Journal of Oral and Maxillofacial Surgery* 45, pp. 56–64.
- Schreuder, W., Jansma, J., Bierman, M. et al., 2007. Distraction osteogenesis versus bilateral sagittal split osteotomy for advancement of the retrognathic mandible: a review of the literature. *Oral & Maxillofacial Surgery* 36, pp. 103–110.
- Stansbury, C., Evans, C., Miloro, M. et al., 2010. Stability of open bite correction with sagittal split osteotomy and closing rotation of the mandible. *Journal of Oral and Maxillofacial Surgery* 68, pp. 149–159.
- Ueki, K., Hashiba, Y., Marukawa, K. et al., 2007. Comparison of maxillary stability after LeFort I osteotomy for occlusal cant correction surgery and maxillary advanced surgery. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* 104 pp. 38–43.
- Witt, D., 1991. Long-term stability of increasing lower anterior facial height with mandibular sagittal osteotomies. Thesis, (Master's). University of Washington.
- Wolford, L., Karras, S. & Mehra, P., 2001. Considerations for orthognathic surgery during growth, part 1: mandibular deformities. *American Journal of Orthodontics and Dentofacial Orthopedics* 119, pp. 95–101.

Orthodontic Treatment of the Transverse Dimension— Assessment of the Evidence

Steven D. Marshall, DDS, MS

Visiting Associate Professor, Department of Orthodontics, University of Iowa College of Dentistry, Iowa City, Iowa

Introduction

Transverse maxillary expansion is a widely used orthodontic treatment for the correction of malocclusion when skeletal and/or dental maxillary transverse insufficiency and posterior crossbite are primary diagnostic features. It is particularly important in eliminating mandibular functional shift, a finding commonly associated with posterior crossbite in early dentition development that, if left untreated, may affect facial symmetry, and temporomandibular joint function. Other reported applications for maxillary expansion include gaining arch perimeter increase (in the absence of posterior crossbite) to facilitate nonextraction edgewise treatment, improving nasal breathing, and improving Class II inter-arch relationships by spontaneous mandibular growth or positioning. In nongrowing patients with transverse maxillary constriction, both orthopedic rapid maxillary expansion and surgically assisted rapid maxillary expansion have been applied to correct posterior crossbite and maxillary arch length deficiency.

The purpose of this chapter is to discuss the various applications of transverse maxillary expansion and assess the evidence supporting its use.

Background

Etiology of Maxillary Constriction

A range of possible causes for maxillary constriction includes genetics, environmental factors, and habits. Posterior crossbite frequently results from transverse maxillary skeletal deficiency, which may have an underlying congenital, developmental, traumatic, or iatrogenic (e.g., cleft palate repair) basis (Betts et al. 1995). Additional causes include asymmetric growth of the maxilla or mandible, discrepant widths of basilar maxilla and mandible, premature loss or prolonged retention of primary teeth, crowding, abnormalities in tooth eruption sequence, impaired nasal breathing during critical growth periods, aberrations in tooth anatomy, and improper function of the temporomandibular joints (Clinch 1966; Higley 1968; Kutin & Hawes 1969; Moyers 1973; Betts et al. 1995). Oral digit habits have also been implicated as an etiologic factor. However, at least one study found no difference in the prevalence of sucking habits when examining patients with or without spontaneous correction of a posterior crossbite (Thilander, Wahlund & Lennartsson 1984).

Prevalence of Posterior Crossbite in the Deciduous and Mixed Dentition

Estimates for the incidence of posterior crossbite range from 5-23% with a greater prevalence of unilateral crossbite coupled with a lateral shift of the mandible. The results of cross-sectional studies on various populations are shown in Table 15.1.

Table 15.1 Incidence of posterior crossbite in various studies.

Author (year)	Population Origin	N	Age Range (years)	Incidence
Helm (1968)	Denmark	455	6–18	11%
Kutin & Hawes (1969)	U.S.	515	3–9	8%
Hanson, Barnard & Case (1970)	U.S.	193	3–5	12%
Thilander, Wahlund & Lennartsson (1984)	Sweden	898	4	10%
Kurol & Bergland (1992)	Sweden	224	3–5	23%
Brunelle et al. (1996)	U.S.	7,000	12–50	10%
Thilander et al. (2001)	Colombia	4,724	5–17	5%
Jonsson et al. (2007)	Iceland	829	31–44	12%
da Silva-Filho et al. (2007)	Brazil	2,016	3–6	19%
Lux et al. (2008)	Germany	494	8.5–9.5	6%
Perillo et al. (2010)	Italy	703	12	14%
Macena, Katz & Rosenblatt (2009)	Brazil	2,750	1.5–5	10%
Borzabadi-Farahani, Borzabadi-Farahani & Eslamipour (2009)	Iran	502	11–14	12%

Table 15.2 Incidence of spontaneous correction of posterior crossbite measured longitudinally from deciduous to mixed or adolescent dentition.

Author (year)	Study Location	N	Age Range Studied (years)	Self-Correction Incidence
Kutin & Hawes (1969)	U.S.	48	5–9	2%
Thilander, Wahlund & Lennartsson (1984)	Sweden	28	4–13	21%
Lindner (1989)	Sweden	38	4–9	17%
Kurol & Bergland (1992)	Sweden	20	4–14	45%

A few studies with small sample sizes have reported wide variation in rates of spontaneous correction from the primary dentition to the mixed dentition or adolescent dentition. These studies are summarized in Table 15.2.

Orthopedic Rapid Maxillary Expansion

Transverse maxillary expansion was introduced in 1860 by Emerson C. Angell. He described the application of a removable jackscrew appliance, activated 7 mm in 2 weeks, that produced a significant maxillary midline diastema (Angell 1860). His suggestion that the appliance produced a separation of the midpalatal suture was roundly criticized by the dental profession (Timms 1999). Another 30 years would pass before numerous case reports and the advent of radiography would support Angell's original insight (Haas 1961; Timms 1999). Many notable U.S. orthodontists of that era, including Angle, Case, Ketcham, and Dewey, maintained an indifference to the procedure. It remained outside mainstream orthodontic therapy until Andrew Haas reintroduced the technique to American orthodontists using a tooth-tissue-borne appliance fabricated with palatal acrylic to maximize lateral translation of the maxillary basal bone and posterior teeth (Haas 1961).

Surgically Assisted Rapid Maxillary Expansion (SARME)

A skeletally mature patient with midpalatal suture synostosis generally will not respond well to orthopedic rapid maxillary expansion (RME). Lack of suture opening, excessive tipping and/or buccal root resorption of anchor teeth, buccal plate bony defects, gingival recession, and expansion asymmetry are potential problems that have been seen when orthopedic RME is attempted in a nongrowing patient (Koudstall et al. 2005). Although closure of the midpalatal suture was originally thought to be the primary resistance to orthopedic RME in nongrowing patients, the resistance to expansion was shown to be mainly from other maxillary articulations, in particular the zygomatic buttresses and the pterygoid junctions (Haas 1961; Isaacson & Ingram 1964; Lines 1975). Surgical release of these sites of resistance reduces RME complications significantly (Bell & Epker 1976).

Surgical procedures for SARME were described as early as 1938 (Brown 1938) but were rarely reported until the 1970s when case reports using simultaneous osteotomies of the piriform aperture, the zygomatic buttresses, the pterygoid junctions, and parallel to the

midpalatal suture were published. Since then opinions vary as to the number of osteotomy sites required for stable surgically assisted expansion (Koudstall et al. 2005).

Maxillary Expansion—Interventions, Outcomes, and Evidence

In the orthodontic literature, there is a wide range of therapeutic interventions under the term *maxillary expansion*. After Haas sparked a resurgence of RME (Haas 1961), an evolution of various RME appliance designs and protocols followed, including removable, tooth-borne, tooth-tissue-borne, and bone-borne expansion appliances with a range of activation times from 0.5 mm per day (rapid maxillary expansion) to 0.25 mm every 2 days (slow maxillary expansion) (Lagravère et al. 2006a). Recently, there has also been a resumed interest in maxillary expansion with the edgewise appliance using a self-ligating variation (Damon 2005). Moreover, the timing and intended therapeutic benefits of these various interventions differ. Maxillary expansion may be applied early or late during growth or in nongrowing patients with reported treatment goals that may include one or more of the following: correction of posterior crossbite, correction of functional mandibular shift associated with posterior crossbite, improved dental arch perimeter length, and improved sagittal inter-arch molar relationship. This heterogeneity of maxillary expansion interventions and the wide variety of outcome variables also poses significant restriction on the strength of the conclusions available to the clinician from systematic reviews on this topic. As such, the clinician, desirous of employing an evidence-based approach to the use of maxillary expansion therapy, is faced with a complex problem of determining what works, for what condition it is best applied, and when to apply it.

It cannot be denied that the many maxillary expansion interventions reported and used in our profession work sufficiently well to support clinical practice. Yet, our profession should continue to strive for information that reveals the most effective and efficient interventions. This duality begs the question, What clinically significant questions about maxillary expansion intervention have been answered from an evidence-based point of view?

Systematic Reviews on Maxillary Expansion

Formulating a key question comparing outcomes to one or more interventions for a particular population is the first step in conducting an evidence-based systematic review (Bader & Ismail 2004). With the variety of interventions and clinical applications for maxillary expansion, assessing the evidence-based information on its effectiveness is limited to questions that have been asked and answered by systematic review. To date, only nine systematic reviews have evaluated nonsurgical maxillary expansion interventions (Harrison & Ashby 2001; Schiffman & Tuncay 2001; Petren et al. 2003; Lagravère et al. 2005a, 2005b, 2005c; Lagravère et al. 2006a; Bondemark et al. 2007; Gordon et al. 2009). These nine articles cover studies published between 1966 and 2009. Two systematic reviews evaluating SARME have evaluated studies published between 1966 and 2008 (Lagravère et al. 2006b; Verstraaten et al. 2009). The following summarizes the answers to specific clinical questions addressed by these systematic reviews.

The Immediate Effects of Rapid Maxillary Expansion

The most current evidence-based information regarding the immediate effect of 2–4 weeks of RME activation comes from a meta-analysis conducted by Lagravère et al. (2006a). Three hundred thirty-seven studies on the skeletal and dental effects of RME, published between 1966 and 2004, were evaluated. Fourteen of the 337 studies were chosen for the meta-analysis. The results show that the immediate treatment effects of RME in the transverse dimension are, on average, 60% dental and 40% skeletal. The average intermolar width gains at the tooth crown and root apex were 6.7 mm and 4.4 mm, respectively. The average increase in basal maxillary width (jugale-jugale) was 2.73 mm, and the average increase in nasal width was 2.14 mm. In the sagittal view, overjet increased 1.29 mm. A point moved anteriorly 0.82 degrees, and B point moved posteriorly 0.62 degrees. Vertical skeletal changes of the mandibular plane to the occlusal plane and the S-N plane were 1.65 degrees and 1.95 degrees, respectively. Although the 14 studies used a variety of appliances, including Haas, banded Hyrax, and bonded Hyrax appliances, interappliance comparisons could not be evaluated.

The Immediate Effects of Slow Maxillary Expansion

Slow maxillary expansion using quad-helix or Minne expansion springs producing 2–10 N of force over 3–4 months is reportedly preferred to RME because of lower forces and better tissue adaptation during expansion (Hicks 1978; Bell 1982). The most current evidence-based information regarding the immediate skeletal and dental effects of slow maxillary expansion comes from a systematic review conducted by Lagravère et al. (2005a). Surveying the literature from 1966 to 2004, they retrieved 31 articles on slow expansion, 8 of which met the authors' inclusion criteria. Their results reflect slow expansion of patients 7–15 years of age. Due to the fact that none of the eight studies used a control group to factor dental and skeletal changes occurring during treatment, the authors could draw no strong conclusions on the dental and skeletal effects of this technique.

Expansion to Correct Posterior Crossbite

Harrison and Ashby (2001) searched for randomized clinical trials (RCTs) and controlled clinical trials (CCTs) with children and/or adults as participants and published between 1970 and 1999 for outcomes resulting from treatments for posterior crossbite. Thirteen trials were evaluated. They concluded that expansion with a removable plate or reduction of cuspal interferences during the late primary/early mixed dentition is effective in eliminating crossbite. They could make no firm conclusions regarding differing outcomes for two-banded versus four-banded hyrax expansion, removable plate versus quad-helix versus hyrax expansion, or banded versus bonded slow maxillary expansion. They could not come to any conclusions on the long-term stability of crossbite correction for any expansion intervention.

The authors' lack of strong conclusions was based on significant limitations in the 13 trials evaluated. None of the trials reported on blinding of the examiners or method of randomization. A majority of the trials neglected to state the number of crossbite patients per group or if crossbites were corrected after treatment. Only 2 of the 13 trials had an adequate sample size to obtain a significant result, and these 2 trials form the basis for the evidence-based conclusions from this review.

In a similar approach, Petren, Bondemark & Soderfeldt (2003) narrowed their population focus to children age 10 years or younger and relaxed their inclusion criteria to include retrospective controlled trials and comparison studies. Their outcome measure was the correction of unilateral posterior crossbite in the early mixed dentition. Their search resulted in 12 trials, 2 of which were RCTs (the two studies that Harrison and Ashby [2001] cited in support of their conclusions). The conclusions by Petren, Bondemark & Soderfeldt (2003) were identical to that of Harrison and Ashby (2001), finding similar shortcomings in the design of the studies evaluated.

The Long-Term Skeletal Effects of Rapid Maxillary Expansion

What are the long-term effects of RME? Lagravère et al. (2005c) evaluated 42 articles for controlled trials that used a control group to factor out changes occurring with normal growth throughout the intervention and retention period. Only three nonrandomized retrospective trials were found. One employed posterior-anterior cephalometry, and two employed lateral cephalometry to measure long-term skeletal change. The authors conclude there is a significant long-term effect on lateral nasal width (+1.5 mm) and that a long-term effect on increased maxillary width may be obtained only in skeletally immature subjects. No significant long-term change in anteroposterior or vertical dimension was noted. The authors state that these conclusions should be interpreted with caution due to potential bias associated with the low number of trials of questionable methodological quality.

The Long-Term Stability of Rapid Maxillary Expansion

What evidence is available concerning the long-term change in maxillary transverse dimension postexpansion (i.e., the amount of expansion remaining more than 5 years after retention)? Of the eight systematic reviews and meta-analyses evaluating maxillary expansion between 1966 and 2007, six included long-term stability as an outcome measure (Harrison & Ashby 2001; Schiffman & Tuncay 2001; Petren, Bondemark & Soderfeldt 2003; Lagravère et al. 2005b, 2005c; Bondemark et al. 2007). Four of the six review articles draw conclusions of inconclusive, equivocal, or at best, weak indirect evidence for long-term stability of maxillary expansion (Harrison & Ashby 2001; Schiffman & Tuncay 2001; Petren, Bondemark & Soderfeldt 2003; Bondemark et al. 2007). Two of the six review articles found a secondary level of evidence of long-term maxillary expansion stability (Lagravère et al. 2005b, 2005c). Table 15.3 summarizes these findings.

The conclusions from these four evidence-based reviews are based on similar methodological weaknesses found in the trials evaluated. These include lack of long-term data, lack of control samples, lack of sample size, selection bias, confounding variables, lack of method or error analyses, lack of statistical analyses, and lack of retention protocol.

The evidence as to whether maxillary expansion is stable long term comes from one retrospective controlled trial on adult subjects and one prospective controlled trial on adolescent subjects. In the adolescent study, posterior crossbite was not an initial condition for any subject. In the adult study, 83% of the subjects began expansion therapy with posterior crossbite. Thus, the evidenced-based answer pertains directly to these conditions. Although RME treatment is considered by many as a stable procedure, there remains a lack of strong evidence for long-term stability of maxillary expansion in adolescent subjects where posterior crossbite is the pretreatment condition. To bolster the evidence for

Table 15.3 Summary of systematic reviews evaluating the long-term stability of maxillary expansion.

Authors (year)	Study Types Included	Study Types Excluded	Studies Evaluated (No.)	Authors' Conclusions
Harrison & Ashby (2001)	Controlled or randomized clinical trials	All others	12	Weak evidence of long-term stability when crossbites are corrected in the primary dentition by removal of premature contacts (based on 2 of the 12 studies).
Schiffman & Tuncay (2001)	Controlled or randomized clinical trials	Trials not reporting long-term postexpansion measures	6	Residual intermolar width postretention was 2.4 mm, which is similar to transverse changes expected with normal growth.
Petren, Bondemark & Soderfeldt (2003)	All clinical trials with subjects age ≤ 10 years of age	Case reports	12	No studies measuring the stability of the correction long term.
Lagravère et al. (2005b)	Controlled clinical trials	Trials not reporting measures >1 year postexpansion	3	Secondary level evidence of long-term stability of dental arch expansion (based on 2 of 3 studies, one adult sample and one adolescent sample).
Lagravère et al. (2005c)	Controlled clinical trials	Trials not reporting measures >1 year postexpansion	1	Weak evidence of long-term skeletal expansion stability using fixed expansion appliances (based on one study).
Bondemark et al. (2007)	All clinical trials	Case reports	3	No meaningful evidence-based conclusions could be made regarding long-term expansion stability.

maxillary expansion stability, well-designed retrospective and prospective controlled trials are needed.

The Effects of RME and SARME on Nasal Airway Dimensions

There is the suggestion that subjects with nasal airflow problems and sleep-disordered breathing problems may benefit from RME or SARME based on literature reports of increase in nasal cavity width, increase in nasal cavity cross-sectional area, increase in nasal volume, and decrease in nasal airway resistance measured by various methods. However, the clinical effectiveness of RME or SARME on nasal function has yet to be determined (for reviews see Neely, Edgin & Gonzalez 2007; Kilic & Oktay 2008). To date, only one review has systematically evaluated the literature in this area. Gordon et al. (2009) retrieved 35 studies using RME or SARME that evaluated nasal airway dimensions in the treated subjects using acoustic rhinometry (AR). The authors' choice of limiting the review to those studies using AR as a measurement tool is based on AR's reasonable estimation of cross-sectional area in the anterior portion of the nasal cavity when compared to more invasive and costly computed tomography and magnetic resonance imaging. As a result of this narrowed focus, four nonrandomized controlled trials were found that met the inclusion criteria. There was a lack of reporting of pretreatment subject characteristics, blinding, reliability measurements, and dropouts in all four studies. These methodological errors did not allow any strong conclusions for the use of RME (or SARME) ". . . as a treatment option for individuals with reduced MCA (minimal cross-sectional area) without an orthodontic indication." (Gordon et al. 2009) They also conclude that nasal cavity changes are expected with maxillary expansion, but the changes are of questionable clinical significance.

The Long-Term Effects of Maxillary Expansion on Arch Perimeter

In clinical orthodontic practice, maxillary expansion may be more often used to increase maxillary arch perimeter than to correct posterior crossbite. This can be accomplished by the use of RME and fixed edgewise treatment (McNamara et al. 2003) or by self-ligating fixed edgewise treatment alone (Damon 2005). The systematic review by Lagravère et al. (2005b) found one study that reported a long-term 6-mm gain in arch perimeter measured 6 years posttreatment that is an outcome of RME and fixed appliance therapy (McNamara et al. 2003). To date, no long-term data exist for arch perimeter gain from fixed edgewise therapy alone.

The Immediate Effects and Long-Term Stability of SARME

The immediate transverse skeletal and dental effects and the long-term stability of SARME were evaluated by one systematic review (Lagravère et al. 2006b). A search of the literature between 1966 and 2005 for human trials measuring SARME changes in transverse dimension on dental casts or radiographs resulted in 12 trials meeting the inclusion criteria. Eight measured immediate changes and 6 trials measured long-term (1 year after orthodontic treatment) changes. All trials were nonrandomized, retrospective, with small sample sizes using tooth-borne expansion appliances. Based on these studies the authors were limited to the following conclusions: The immediate effects of SARME are in increase in intermolar width (means ranging from 7.1 to 8.7 mm) and a smaller increase in intercanine

width (means ranging from 4.9 to 5.2 mm). Vertical or sagittal changes measured by cephalometrics were judged as clinically insignificant. Relapse of transverse intermolar width 1 year after orthodontics was 0.5–1 mm, supporting the notion that SARME is less prone to relapse than RME.

The Effects of SARME Using a Bone-Borne Expansion Appliance

The effects of SARME using a bone-borne expander was evaluated by one systematic review (Verstraaten et al. 2009). The authors searched the literature published between 1966 and 2008 for RCTs, CCTs, and case reports with $N \geq 5$ involving adults or adolescents that had undergone SARME with a bone-borne expansion appliance. Only 9 prospective and 1 retrospective case reports were available for review. The authors call attention to the difficulty in performing a quantitative systematic review due to the variety of appliances (five different appliances used), surgical cuts (five different surgical techniques used), and expansion protocols (0.33–1.0 mm expansion per day beginning 1 to 7 days after surgery with the expansion end point not reported). Only 7 of the 10 case reports performed quantitative measurements. The assumption that bone-borne SARME results in less molar tipping than tooth-borne SARME was not supported by 1 study in this review that showed significant palatal tipping of molars. There is a suggestion (by 1 case report of 20 subjects) that SARME without pterygoid dysjunction results in more expansion of the anterior maxilla compared to SARME with pterygoid dysjunction, which results in similar anterior and posterior expansion width. In summary, the authors could not find evidence of a bone-borne advantage over tooth-borne SARME.

Spontaneous Improvement of Class II Molar Relationship Toward Class I with RME

There has been the suggestion and preliminary data (McNamara 2000; McNamara et al. 2010) that early intervention with RME for Class II patients results in spontaneous improvement in inter-arch molar relationship toward class I. To date there are no systematic reviews pertaining to this question.

Future Directions

It is apparent from the 10 systematic reviews on maxillary expansion that better research designs for this topic are needed. As case reports have been the majority of work forming the basis for our understanding of maxillary expansion, authors of systematic reviews have culled through hundreds, even thousands of articles to arrive at a dozen or fewer that fulfill the inclusion requirements for sound clinical research. Even those studies meeting inclusion requirements are prone to significant bias and weakness due to methodological errors and small sample sizes. Heterogeneity in data collection, protocol, retention and follow-up were common criticisms of the trials evaluated. Another consistent criticism was lack of reporting of key factors such as blinding, method of randomization, pretreatment patient characteristics, and reproducibility error in measurements. Improvement will require a better understanding of the planning and suitable methodology required for meaningful clinical trials. Multicenter studies could improve the problem of inadequate sample size. As a model for this, the Eurocran Distraction Study (Kuijpers-Jagtman & Wijdeveld 2005)

employs 14 European centers providing distraction osteogenesis. The centers are coordinated with prospective registration of distraction patients and a standardized protocol from pretreatment through 24 months postsurgery for each patient treated.

Randomized Clinical Trials

In the 10 systematic reviews on maxillary expansion, only five randomized trials were found. It has been reasoned that there is a limit to the clinically significant questions in orthodontics that can be explored by the randomized clinical trial (Johnston 2000). This limit is based on ethical requirements that cannot be met for particular clinical questions. Comparison of appliance types and expansion protocols may support randomization. On the other hand, there is a low probability that a potential study subject with bilateral posterior crossbite would consent to be randomized to a “no treatment” group. RCTs remain our gold standard, but to be a practical approach for questions regarding maxillary expansion, randomization into different active treatments may be necessary rather than into treatment versus no-treatment groups.

Nonrandomized Retrospective Clinical Trials

The most important effect of randomization in a clinical trial is the minimization of bias in assigning the subjects to treatments. In nonrandomized retrospective trials selection bias must always be considered. It can be minimized by avoiding inclusion of patients based on treatment outcome and selecting patients who show morphologically similar pretreatment characteristics that would have made them eligible for any treatment group in the trial if chosen prospectively. Discriminate analysis of the pretreatment characteristics of a sample population can help in this regard by teasing out a subset of subjects who show marked similarity in pretreatment characteristics (i.e., not at the extremes of the sample) and for whom differences in treatment outcome could be attributed to differences between interventions (Johnston 2002).

Questions for Future Research

The ultimate goal in our use of any orthodontic intervention on a patient is to understand its effectiveness in treating a problem. Given the heterogeneity of malocclusion and maxillary expansion interventions, many specific questions about effectiveness remain unanswered. For example, today, from the evidence-based point of view, we cannot adequately answer the question, How effective is RME in providing a stable correction of posterior crossbite in growing individuals? Other clinical questions needing evidence from well-designed trials include the following:

1. How does the growth status of the subject influence the long-term effect of RME? Does the growth pattern influence the effect?
2. What are the long-term skeletal effects of therapy that includes RME? Is the immediate RME effect on buccal alveolar bone harmful long term?
3. Comparing rapid versus slow expansion, how do the protocols differ in terms of the outcomes they achieve? How does their effectiveness compare for gaining a stable change in the dental arch?

4. Does expansion with a self-ligating edgewise appliance produce long-term dental arch change comparable to therapy that includes slow or rapid maxillary expansion?
5. What are the long-term effects of RME on impaired nasal breathing?
6. Does early intervention with RME facilitate a growth-mediated anterior positioning of the mandibular dentition?

It is apparent that much work lies ahead to advance the cause and bolster the support of evidence-based orthodontics. The preservation and advancement of our profession depends on our duty toward this worthwhile goal.

References

- Angell, E., 1860. Treatment of irregularities of the permanent or adult teeth. *Dental Cosmos* 1, pp. 540–544.
- Bader, J. & Ismail, A., 2004. Survey of systematic reviews in dentistry. *Journal of the American Dental Association* 135, pp. 464–471.
- Bell, R.A., 1982. A review of maxillary expansion in relation to rate of expansion and patient's age. *American Journal of Orthodontics* 81, pp. 32–37.
- Bell, W.H. & Epker, B.N., 1976. Surgical-orthodontic expansion of the maxilla. *American Journal of Orthodontics* 70(5), pp. 517–528.
- Betts, N., Vanarsdall, R., Barber, H. et al, 1995. Diagnosis and treatment of transverse maxillary deficiency. *International Journal of Adult Orthodontics and Orthognathic Surgery* 10, pp. 75–96.
- Bondemark, L., Holm, A.K., Hansen, K. et al., 2007. Long-term stability of orthodontic treatment and patient satisfaction. *The Angle Orthodontist* 77, pp. 181–191.
- Borzabadi-Farahani, A., Borzabadi-Farahani, A., Eslamipour, F., 2009. Malocclusion and occlusal traits in an urban Iranian population. An epidemiological study of 11- to 14-year-old children. *European Journal of Orthodontics* 31, pp. 477–484.
- Brown, G.V., 1938. *The surgery of oral and facial diseases and malformation*. 4th ed., London: Kimpton.
- Brunelle, J.A., Bhat, M. & Lipton, J.A., 1996. Prevalence and distribution of selected occlusal characteristics in the U.S. population 1988–1991. *Journal of Dental Research* 75, pp. 703–713.
- Clinch, L., 1966. Development of deciduous and mixed dentition. *The Dental Practitioner and Dental Record* 17, pp. 135–145.
- Damon, D.H., 2005. Treatment of the face with biocompatible orthodontics. In: Graber, T.M., Varnarsdall, R.L. & Vig, K.W., editors. *Orthodontics current principles and techniques*. St. Louis: Elsevier Mosby.
- da Silva Filho, O.G., Santamaria, M. & Capelozza Filho L., 2007. Epidemiology of posterior cross-bite in the primary dentition. *Journal of Clinical Pediatric Dentistry* 32(1), pp. 73–78.
- Gordon, J.M., Rosenblatt, M., Witmans, M. et al., 2009. Rapid palatal expansion effects on nasal airway dimensions as measured by acoustic rhinometry: a systematic review. *The Angle Orthodontist* 79, pp. 1000–1007.
- Haas, A.J., 1961. Rapid palatal expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. *The Angle Orthodontist* 31, pp. 73–90.
- Haas, A.J., 1965. The treatment of maxillary deficiency by opening the midpalatal suture. *The Angle Orthodontist* 35, pp. 200–217.
- Hanson, M., Barnard, L. & Case, J., 1970. Tongue thrust preschool children. Part II: dental occlusal patterns. *American Journal of Orthodontics* 57, pp. 15–22.

- Harrison, J.E. & Ashby, D., 2001. Orthodontic treatment for posterior crossbites. *Cochrane Database of Systematic Reviews* (1). Article No.: DC000979.
- Helm, S., 1968. Malocclusion in Danish children with adolescent dentition: an epidemiologic study. *American Journal of Orthodontics* 54, pp. 352–366.
- Hicks, E.P., 1978. Slow maxillary expansion: a clinical study of the skeletal versus dental response to low-magnitude force. *American Journal of Orthodontics* 73, pp. 121–141.
- Higley, L., 1968. Crossbite mandibular malposition. *Journal of Dentistry for Children* 35, pp. 221–223.
- Issacson, R.J. & Ingram, A.H., 1964. Forces produced by rapid maxillary expansion I: forces present during treatment. *The Angle Orthodontist* 34, pp. 256–260.
- Johnston, L.E., 2002. Moving forward by looking back: ‘retrospective’ clinical studies. *Journal of Orthodontics* 29, pp. 211–226.
- Johnston, L.E., 2000. Occlusal grinding in the primary dentition effective in preventing a posterior crossbite *Evidence-Based Dentistry* 2, p. 19.
- Jonsson, T., Arnlaugsson, S., Karlsson, K.O. et al., 2007. Orthodontic treatment experience and prevalence of malocclusion traits in an Icelandic adult population. *American Journal of Orthodontics and Dentofacial Orthopedics* 131, pp. 8.e11–8.e18.
- Kilic, N. & Oktay, H., 2008. Effects of rapid maxillary expansion on nasal breathing and some naso-respiratory and breathing problems in growing children: a literature review. *International Journal of Pediatric Otorhinolaryngology* 72, pp. 1595–1601.
- Koudstall, M.J., Poort, K.G.H., van der Wal, E.B. et al., 2005. Surgically assisted rapid maxillary expansion (SARME): a review of the literature. *International Journal of Oral and Maxillofacial Surgery* 34, pp. 709–714.
- Kuijpers-Jagtman, M.J., Wijdeveld, M.G.M.M., 2005. The Eurocran distraction study. *World Journal of Orthodontics* 6, pp. 95–96.
- Kurol, J., Bergland, L., 1992. Longitudinal study and cost-benefit analysis of the effect of early treatment of posterior cross-bites in the primary dentition. *European Journal of Orthodontics* 14, pp. 173–179.
- Kutin, G., Hawes, R., 1969. Posterior crossbites in the deciduous and mixed dentitions. *American Journal of Orthodontics* 56, pp. 491–504.
- Lagravère, M.O., Major, P.W. & Flores-Mir, C., 2005a. Skeletal and dental changes with fixed slow maxillary expansion: a systematic review. *Journal of the American Dental Association* 136, pp. 194–199.
- Lagravère, M.O., Major, P.W. & Flores-Mir, C., 2005b. Long-term dental arch changes with rapid maxillary expansion: a systematic review. *The Angle Orthodontist* 75, pp. 155–161.
- Lagravère, M.O., Major, P.W. & Flores-Mir, C., 2005c. Long-term skeletal changes with rapid maxillary expansion: a systematic review. *The Angle Orthodontist* 75, pp. 1046–1052.
- Lagravère, M.O., Heo, G., Major, P.W. et al., 2006a. Meta-analysis of immediate changes with rapid maxillary expansion treatment. *Journal of the American Dental Association* 137, pp. 44–53.
- Lagravère, M.O., Major, P.W. & Flores-Mir, C., 2006b. Dental and skeletal changes following surgically assisted rapid maxillary expansion. *International Journal of Oral and Maxillofacial Surgery* 35, pp. 481–487.
- Linder, A., 1989. Longitudinal study of the effect of early interceptive treatment in 4-year old children with unilateral cross-bite. *Scandinavian Journal of Dental Research* 97, pp. 432–438.
- Lines, P.A., 1975. Adult rapid maxillary expansion with corticotomy. *American Journal of Orthodontics* 67, pp. 44–66.
- Lux, C.J., Ducker, B., Pritsch, M. et al., 2008. Occlusal status and prevalence of occlusal malocclusion traits among 9-year old schoolchildren. *European Journal of Orthodontics* 31, pp. 294–299.
- Macena, M.C., Katz, C.R. & Rosenblatt, A., 2009. Prevalence of a posterior crossbite and sucking habits in Brazilian children age 18–59 months. *European Journal of Orthodontics* 31(4), pp. 357–361.

- McNamara, J.A., 2000. Early intervention in the transverse dimension: is it worth the effort? *American Journal of Orthodontics and Dentofacial Orthopedics* 121, pp. 572–574.
- McNamara, J.A., Baccetti, T., Franchi, L. et al., 2003. Rapid maxillary expansion followed by fixed appliances: a long-term evaluation of changes in arch dimensions. *The Angle Orthodontist* 73, pp. 344–353.
- McNamara, J.A., Sigler, L.M., Franchi, L. et al., 2010. Changes in occlusal relationships in mixed dentition patients treated with rapid maxillary expansion. *The Angle Orthodontist* 80, pp. 230–238.
- Moyers, R., 1973. *Handbook of orthodontics*. 3rd ed., Chicago: Year Book Medical Publishers, pp. 530–542.
- Neely, W.W., Edgin, W.A. & Gonzalez, D.A., 2007. A review of the effects of expansion of the nasal base on nasal airflow and resistance. *Journal of Oral and Maxillofacial Surgery* 65, pp. 1174–1179.
- Perillo, L., Masucci, C., Ferro, F. et al., 2010. Prevalence of orthodontic treatment need in southern Italian schoolchildren. *European Journal of Orthodontics* 32, pp. 49–53.
- Petren, S., Bondemark, L. & Soderfeldt, B., 2003. A systematic review concerning early orthodontic treatment of unilateral posterior crossbite. *The Angle Orthodontist* 73, pp. 588–596.
- Schiffman, P.A. & Tuncay, O.C., 2001. Maxillary expansion: a meta analysis. *Clinical Orthodontic Research* 4, pp. 86–96.
- Thilander, B., Wahlund, S. & Lennartsson, B., 1984. The effect of early interceptive treatment in children with posterior crossbite. *European Journal of Orthodontics* 6, pp. 25–34.
- Thilander, B., Pena, L., Infante, C. et al., 2001. Prevalence of malocclusion and orthodontic treatment need in children and adolescents in Bogota, Columbia. An epidemiological study related to different stages of dental development. *European Journal of Orthodontics* 23, pp. 153–167.
- Timms, D.J., 1999. The dawn of rapid maxillary expansion. *The Angle Orthodontist* 69, pp. 247–250.
- Verstraaten, J., Kuijpers-Jagtman, A.M., Mommaerts, M.Y. et al., 2010. A systematic review of the effects of bone-borne surgical assisted rapid maxillary expansion. *Journal of Cranio-Maxillofacial Surgery* 38, pp. 166–174.

Class III Malocclusion— The Evidence on Diagnosis and Treatment

**Joseph G. Ghafari¹, DMD, Ramzi V. Haddad², DDS, MS,
Maria E. Saadeh³, DDS, MS**

¹Professor and Head, Orthodontics and Dentofacial Orthopedics, American University of Beirut Medical Center, Beirut, Lebanon; Professor of Orthodontics, Lebanese University, Beirut, Lebanon; Adjunct Professor of Orthodontics, New York University, New York

²Instructor, Orthodontics and Dentofacial Orthopedics, American University of Beirut Medical Center, Beirut, Lebanon

³Clinical Associate, Orthodontics and Dentofacial Orthopedics, American University of Beirut Medical Center, Beirut, Lebanon; Clinical Instructor, Lebanese University, Beirut, Lebanon

Introduction

Class III, division 1 is characterized [in both lateral halves of the dental arches] by mesial occlusion [that] is slightly more than one half the width of a single cusp on each side, but in cases that have been allowed to develop—and these cases are always progressive—the mesial occlusion becomes greater, even to the full width of a molar, or more.

Edward Hartley Angle, 1907

Angle's Classification

Angle's description of Class III malocclusion (Figure 16.1), also known as mesiocclusion, in its symmetrical (division 1) and asymmetric (subdivision) patterns focuses not only on the occlusion between the teeth but also on individual variation. Angle describes



Figure 16.1 Class III, subdivision 1, according to Angle.

“considerable crowding, especially in the upper arch, and lingual inclination of the lower incisors and canines.” Although Angle’s classification has been used for over 100 years around the globe, his assumptions on etiology and diagnosis of the malocclusion lack definitive evidence. These assumptions include the relation of mandibular incisor retroclination to lower lip pressure “in the effort to close the mouth and disguise the deformity” and his only explanation for the etiology of Class III, the enlarged tonsils associated with the “habit of protruding the mandible” to afford “relief in breathing.”

Angle assigns the “proportion” of Class III occurrence among 1000 malocclusions: Division—Bilaterally mesial (34/1000); subdivision—unilaterally mesial (8/1000). The incidence thus amounts to 4.2%, nearly similar to the reported incidence in American children in the 1970s (3%, Kelly, Sanchez & Van Kirk 1973) and 1990s (3.2%, Brunelle, Bhat & Lipton 1996; Proffit, Fields & Moray 1998; Proffit 2000). Higher incidences are reported among Asian populations.

General Characteristics

Angle’s observation on incisor retroclination preceded the age of cephalometrics, which demonstrated a corresponding proclination of maxillary incisors, reflecting dentoalveolar compensation by maxillary and mandibular incisors to an underlying skeletal discrepancy characterized by maxillary retrognathism, mandibular prognathism, or both.

Sometimes the incisal compensation is expressed with incisal edge-to-edge rather than crossbite, yet it is compatible with molar mesiocclusion and an underlying Class III pattern. Variations and gradients of severity include the complex differentiation between macrognathism and prognathism in reference to the skeletal bases and between alveolar and skeletal bases. Therefore, the mosaic arrangement of the “parts” requires careful diagnosis, albeit the evidence of tailoring treatment modalities to specific diagnoses is not fully available. This shortcoming is related in great part to the availability of limited approaches to treatment and the inability of treatment to affect the cranial and facial skeletal parts compared to the relatively easier handling of dental components.

In a retrospective study of mesiocclusion that comprised a group of Class II malocclusions, we investigated the underlying craniofacial morphology. Critical conclusions included (Figure 16.2) the following:

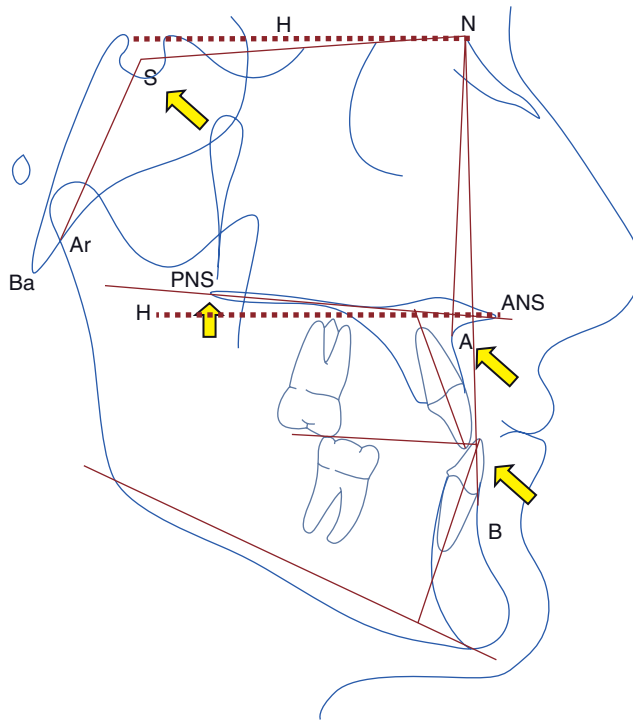


Figure 16.2 Graphic representation of anterior crossbite, superior-posterior tip of the palatal plane (ANS-PNS) relative to horizontal (H), and high position of sella (S) relative to nasion (N) leading to reduced angle between SN and H. The morphological pattern may result from the transfer of forces generated by the anterior crossbite through the maxilla to the level of the cranial base. Findings on Class III craniofacial morphology also indicate: more reduction of SNA than SNB relative to their respective average values, and smaller saddle angle (N-S-Ar or N-S-Ba) in comparison with Class II morphology. Ar, articulare; Ba, basion.

1. The prevalence of maxillary retrognathism is more than previously thought because its occurrence is more severe ($SNA = 78.04 \text{ degrees} \pm 4.04 \text{ degrees}$; norm = $82 \text{ degrees} \pm 2 \text{ degrees}$) than mandibular prognathism ($SNB = 81 \text{ degrees} \pm 2 \text{ degrees}$; norm = $80 \text{ degrees} \pm 2 \text{ degrees}$), the angles SNA and SNB yielding differences of 4 degrees and 1 degree from the respective norms.
2. A more cephalad position of the anterior cranial base is underscored by a higher position of sella relative to nasion, concomitant with the previously described decrease in the saddle angle (nasion-sella-basion).
3. A previously unreported superior-posterior tip of the palatal plane.
4. Possibility of environmental induction of mesiocclusion: an anterior crossbite, not necessarily related to genetic factors but sustained by mandibular forward positioning caused by occlusal interferences, habits, or to improve breathing,

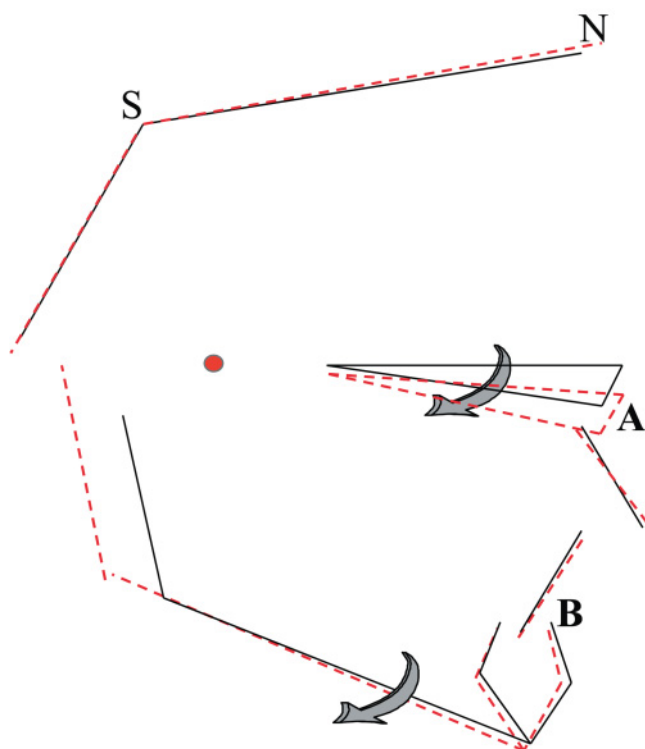


Figure 16.3 Treatment with straight-pull headgear inserted in tubes attached to maxillary first molars resulted in downward (clockwise) rotation of the palatal plane around a center (red circle) nearly 4 cm (on average) posterior to PNS. Rotation in the same direction would occur from the sustained effect of an anterior crossbite but probably with a center of rotation more anteriorly located. (Vertical changes in mandible are not represented. Data from Efstratiadis et al. 2005.)

may induce forces that produce maxillary retrognathism that otherwise would not exist and affect the palatal tip through the occlusion (in a manner similar to the action of a headgear; Figure 16.3).

5. The thickness of the soft tissue envelope, which may differ from one region to another, can compensate or exacerbate the regional diagnosis.

Three-dimensional imaging of the craniofacial system has not yet generated new knowledge of Class III morphology to enable more accurate diagnosis, the aim of which is to formulate a corresponding individualized treatment approach.

Pseudo Class III

Pseudo Class III is also called functional crossbite, mandibular displacement, or positional malrelationship (Moyers 1988) because the mandible shifts forward after initial interference, often on canines or more posterior teeth. Compared with Class I malocclusion,

pseudo Class III is characterized by retroclined maxillary incisors, retrusive upper lip, decreased midface length, and increased maxillary-mandibular difference (Rabie & Gu 2000; Ngan 2006). Because of closer to normal skeletal features, maxillary and mandibular incisors do not show the typical compensatory inclinations, facilitating resolution of the malocclusion by orthodontic means. In “true” Class III, functional forward shift may coexist with the underlying skeletal discrepancy.

Diagnostic Considerations

Available evidence on the development of Class III suggests the assessment of references used for more accurate cephalometric diagnosis. Maxillary and mandibular positions are commonly gauged by the angles SNA and SNB. The position of sella can induce misinterpretation of data if not corrected to the natural head position “true” horizontal. A high sella relative to nasion would yield smaller SNA and SNB values when corrected, thus less maxillary and mandibular prognathism; a low position of sella would have opposite consequences (Figure 16.4). Regarding SNB specifically, the deeper the overbite or the more anterior functional positioning of the mandible, the greater the SNB angle, thus the inference of more mandibular prognathism. Accurate appreciation of SNB would require “bite opening” or “rotating” the image of the mandible on the tracing to near normal overbite (20%–30%). Such exercise is further rationalized with anterior (functional) mandibular displacement, particularly in the diagnosis of pseudo Class III. These issues are not accounted for in research on Class III malocclusion.

Etiology of Class III Malocclusion

Class III is often associated with the image of mandibular prognathism (Figure 16.5). The role of genetics and environment in establishing the size and position of the craniofacial components is complex and not yet fully unraveled.

Environmental factors are increasingly recognized as potential determinants of at least individual malocclusions. King, Harris & Tolley (1993) reported the potential environmental influence on and lower genetic components of craniofacial size and form, a finding that would suggest the possibility of minimizing or avoiding the full expression of Class III, despite its ranking as the first most likely deformity to run in families (Proffit 2007). Our research findings and enunciation of the concept of developmental or “intragrowth” orthopedics support the effect of the environment (sustained early anterior crossbite) potentially affecting the position of the maxilla (Figure 16.6; Ghafari 2004). Development and/or severity of the maxillary retrognathism may be generated by functional forces initiated by mandibular anterior position and transferred through the occlusion, particularly in instances of deep overbite maintained during a long period of growth (Ghafari & Haddad 2005).

Nasal obstruction also induces a forward position of the mandible that helps clear the airway and reduce mouth breathing (Macari & Ghafari 2006). This theory was Angle’s only explanation for the etiology of Class III, beginning before or around the time of eruption of the first permanent molars and “always associated at this age with enlarged tonsils.” Angle further stated his “conviction” that other etiologic factors are of minor importance and that early treatment of the “throat” and correction of the molar occlusion and its retention for a few months would eliminate the problem. Angle also assigned Class

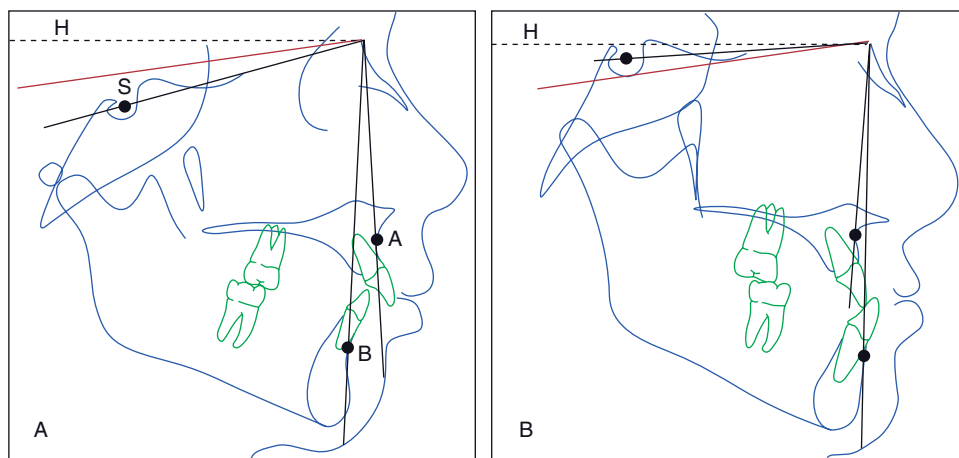


Figure 16.4 Variation in the position of sella (S) relative to nasion (N) results in an upward (cephalad) or downward (caudad) inclination of the SN reference line and consequently an overestimate and underestimate of the jaws' anteroposterior positions (SNA and SNB).

(A) Lateral cephalometric tracing of a boy 10 years, 5 months old with a Class II, division 1, malocclusion. The inclination of the SN line to the horizontal affects the values of SNA and SNB and the interpretation of sagittal jaw relationship. While the difference in ANB = 8 degrees (norm: 2–3 degrees), SNA = 80 degrees (norm: 82 degrees) and SNB = 72 degrees (norm: 79–80 degrees), suggesting that the sagittal discrepancy is caused by a retrognathic mandible. However, the cant of SN to the horizontal recorded from the natural head position is 15 degrees instead of the norm of 8 degrees (7–9 degrees). When the difference of 7 degrees (15 degrees minus 8 degrees) is added to the values of SNA and SNB to correct for the SN inclination, the angular measurements become SNA = 80 degrees + 7 degrees = 87 degrees; SNB = 72 degrees + 7 degrees = 79 degrees, yielding the correct diagnosis of maxillary prognathism and “normal” mandibular position.

(B) Lateral cephalometric tracing of a boy 14 years, 10 months old with Class III malocclusion with ANB difference of –3 degrees, seemingly relating a normally positioned maxilla (SNA = 82 degrees) and a prognathic mandible (SNB = 85 degrees). Yet, correction of the SN cant to horizontal from an acute 4 degrees to the average of 8 degrees decreases the SNA angle to 78 degrees (82 degrees – 4 degrees), and the SNB angle to 81 degrees (85 degrees – 4 degrees), adjusting the diagnosis to maxillary retrognathism (Ghafari 2006, Ghafari et al. 2007a).

II development at least partially to mouth breathing (1907). Angle's hypotheses are not supported by definitive evidence, yet the suggested mechanism should be valid for at least a proportion of patients.

Based on our research findings, we postulate that a Class III malocclusion underlined with mandibular prognathism is mainly genetic in nature, whereas a mesiocclusion associated with maxillary retrognathism is the result of environmental induction (which may



Figure 16.5 Mandibular prognathism is best illustrated in the inherited prognathism within the Habsburg dynasty. Charles II of Spain, the “pathetic victim” of Habsburg inbreeding.



Figure 16.6 Class III malocclusion with maxilla fully embedded within prognathic mandible (see other views in Figure 16.12).

include the restraining effect of an inherited macro and/or prognathic mandible as a primary or secondary factor of inhibiting maxillary forward growth). This premise implies the proper selection of a “true” Class III in researching the genetics of Class III. Such studies should not include maxillary retrognathism, at least not without the presence of a prognathic mandible with increased mandibular size by one standard deviation or more.

Foundations and Variations of Treatment

“[Class III malocclusions are] by far the worst type of deformities the orthodontist is called upon to treat, and when they have progressed until the age of sixteen or eighteen, or after the jaws have become developed in accordance with the malpositions of the teeth, the case has usually passed beyond the boundaries of malocclusion only, and into the realm of bone deformities, for which, with our present knowledge, there is little possibility of affording relief through orthodontic operations.”

Edward Hartley Angle, 1907

How different is the state of the art of treatment of Class III malocclusions over a century after this writing by the definer of the deformity? As the statement implies, treatment is considered differently in growing and adult patients.

Early Treatment

Treatment Approach

With increasing emphasis on repositioning the maxilla rather than the mandible in orthognathic surgery (Proffit, Turvey & Phillips 1996), the focus on maxillary orthopedics in the early treatment of the malocclusion is not surprising. Chin cups to restrain mandibular growth have largely been replaced by face masks (reverse headgears) to protract the maxilla, often with rapid palatal expansion. The rationale for expansion is to minimize the resistance of bony buttresses around the maxilla, splint the maxillary teeth, and correct a posterior crossbite when present. In the primary dentition, fixed palatal expanders or other appliances, such as the Porter arch and quad helix, may be used to achieve expansion. When no expansion is needed, passive appliances (e.g., Nance holding arch) are used.

An important clinical observation is warranted: unless a posterior crossbite exists, palatal expansion is not needed for transverse occlusal correction. An anticipated forward positioning of the maxillary dentition relative to the mandibular teeth produces an increased maxillary width (Figure 16.7). Therefore, many practitioners use the face mask without

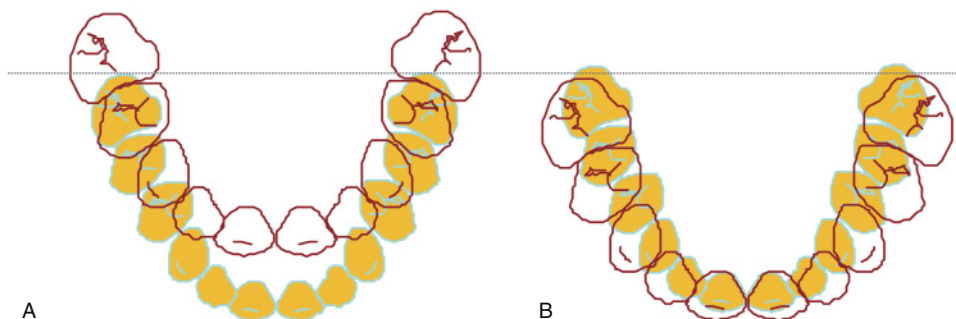


Figure 16.7 (A) Maxillary arch (white) in normal transverse relation with mandibular arch (orange) in Class III malocclusion. (B) When arches are approximated into normal Class I relationship, maxillary width increases relative to mandibular breadth at the level of molars and premolars. The opposite is true in Class II malocclusions.

palatal expansion. However, long-term studies are based on the combined use of these appliances and on treatment in the mixed dentition. Most treatment regimens in the primary dentition are based on expert opinion or case reports or series.

Existing Evidence

Because of the need for long-term evaluation of early treatment and a lower incidence of Class III malocclusion within Caucasian populations, long-term studies of Class III treatment are limited. Research including the highest level of evidence indicates the following conclusions:

Treatment Timing: Treat Early for More Effect The available evidence emphasizes the efficiency of early treatment, however, more because of its potential effect relative to late treatment. Based on bone age assessment, Suda et al. (2000) determined “more pronounced” treatment effects in younger children. In a meta-analysis, Kim et al. (1999) concluded that protraction face mask therapy is effective in growing patients but to a lesser degree in those older than age 10 years.

Accordingly, treatment in the primary dentition should be more efficient, and some supporting authors have hypothesized potential effect on the cant of the cranial base or saddle angle (Delaire 1980; Deshayes 2006) that would enhance more posterior positioning of the glenoid fossa and thus less prognathic mandible. Advocating optimal treatment timing for face mask therapy in the deciduous or early mixed dentition, Ngan (2006) cites the benefits to include favorable sutural response, elimination of any functional discrepancy between centric occlusion and centric relation, and improvement in facial profile and self-esteem.

Another reason for early treatment that requires focused research is its potential to reduce the worsening of the developing dentofacial dysmorphism. Given the increased severity in maxillary retrognathism if sustained by a forward mandibular position, the sooner the anterior crossbite is eliminated, the closer to normal development would be the dentofacial complex, especially maxillary development. Consequently, future treatment may be reduced to only orthodontic treatment (tooth alignment or compensation of dental inclination over bone) or limited orthognathic surgery (only mandibular surgery or if both jaws are involved, one instead of multiple-piece maxillary surgery).

Treatment Modality: Palatal Expansion May Not Be Required and Chin Cup Success Is Questionable Palatal expansion is often indicated, particularly in the presence of maxillary constriction and crowding. In a meta-analysis, Kim et al. (1999) reported similar protraction with or without expansion, though the average treatment duration was longer without expansion. While protraction combined with an initial period of expansion was thought to provide more significant skeletal effects (Kim et al. 1999), such as greater forward movement of point A (Baik 1995), the need for expansion absent a transverse discrepancy (skeletal/dental crossbite) was not supported by the results of a prospective randomized clinical trial (Vaughn et al. 2005). The authors evaluated face mask treatment with and without palatal expansion in children at mean initial ages of 7.4 and 8.1 years, respectively, compared with an observation group (6.6 years). The treatment modalities produced equivalent dentofacial changes. Other authors concurred (Tortop, Keykubat & Yuksel 2007). Varied modalities have been advanced that comprise bonded splints with

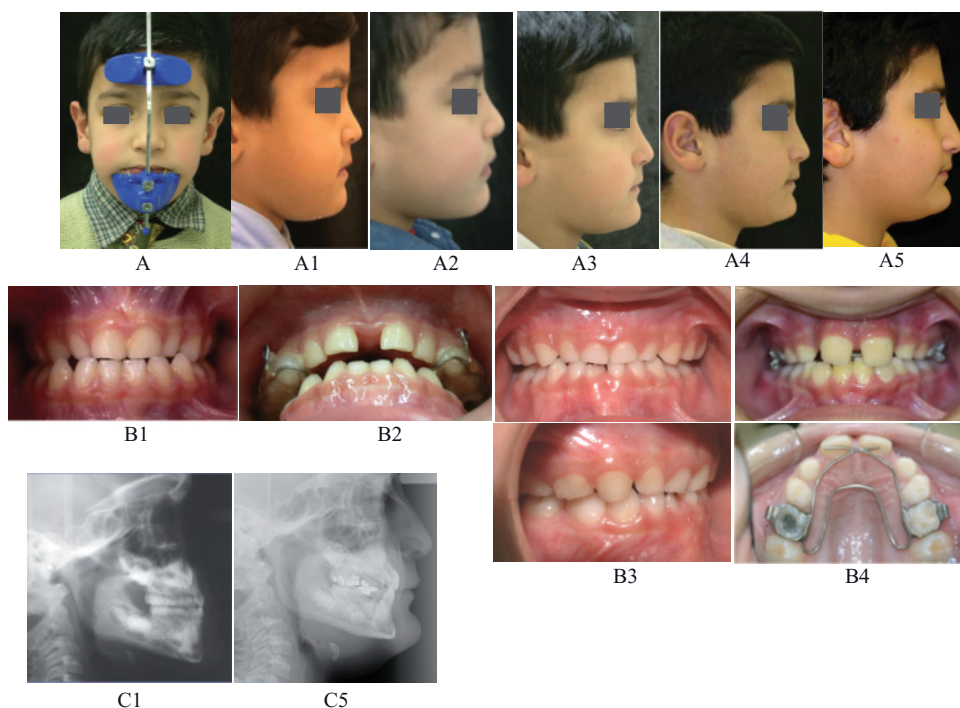


Figure 16.8 Treatment of Class III malocclusion ($ANB = 1.5$ degrees; incisors edge to edge) in 5-year-old boy with primary dentition, using a combination of palatal expander and face mask (A). Photographs of profile (A1–A5), occlusion (B1–B4), and cephalographs (C1, C5) illustrate changes at different times: 1, initial; 2, 17 days after initiation of treatment; 3, 14 months; 4, 3 years, and 5, 6 years. Note the following details: (B2) diastema is the result of palatal expansion with bonded appliance over primary canines and molars; overjet is overcorrected. (B3) Following interrupted retention of phase 1 results, retroclination of primary incisors, though not in crossbite at time T3; (B4) permanent incisors developed in upright and retroclined position are proclined with Porter arch to develop positive overjet at time T4.

bite blocks for expansion or the addition of adjunct appliances, further demonstrating the variability of approaches to the same strategy. No evidence is available on more or less effectiveness over the basic strategy.

Our observations regarding palatal expansion and face mask in the primary dentition, with overcorrection and removable retention, include the possibility of emergence of the permanent incisors in retroclination, although skeletal changes seem more stable (Figure 16.8). Research is needed on this particular regimen. Thus, the use of a Porter arch or quad helix appliance might be sufficient to correct the anterior crossbite in the primary dentition, with a possible combination of palatal expansion with face mask in the mixed dentition.

A chin cup was initially thought to reduce the growth of a prognathic mandible. Although animal studies indicated the possibility of altering condylar growth (Petrovic, Stutzmann & Oudet 1975; Copray, Jansen & Duterloo 1985; Vardimon et al. 1994), clinical

research reveals initial changes within the skeleton that were rarely maintained during pubertal growth (Sugawara & Mitani 1993). The face mask includes a chin cup component (Figure 16.8). The separate effect of the chin cup versus maxillary protraction is not known and would be difficult to determine. The chin cup may have an additive influence, maximizing the effect of the protraction, and/or mandibular rotation.

Mandibular headgear was used in Class III treatment, followed by fixed appliances with long-term improvement that contrasted with lack of self-improvement in corresponding controls (Baccetti et al. 2009). The results show compensatory changes that might be achieved with fixed appliances that would distalize the mandibular teeth. More research is required to explore such approaches.

Treatment Is Better Than No Treatment Pangrazio-Kulbersh et al. (2007) reported that continued anterior growth after protraction is removed was greater than in control subjects. In a cohort study, they compared protraction treatment with surgical correction 7 years posttreatment, along with a corresponding control group. The authors found a “striking” general similarity between the protraction and surgical groups, suggesting that appropriate orthodontic treatment may avoid surgery.

Overtreatment Is Better for Stability of Results “Aggressive overcorrection of Class III appears advisable.” Westwood et al. (2003) made this conclusion from a cohort study of the long-term effects of Class III treatment with rapid maxillary expansion and face-mask therapy followed by a second phase of treatment with preadjusted edgewise fixed appliances (average of 27 months). Between both treatment phases, patients wore a removable maxillary “stabilization plate.” In a few instances, phase 2 followed phase 1 immediately. The authors evaluated the stability of maxillary protraction in 34 patients at pretreatment (average age: 8 years, 3 months) and posttreatment (14 years, 10 months) compared with matched untreated controls. The treated patients had a more favorable skeletal change than control subjects in whom the mesiocclusion was maintained (Figure 16.9). However, a close evaluation of the published illustrations reveals compensatory proclination of maxillary incisors and maintenance of retroclination of mandibular incisors, supported by the reported use of Class III elastics with fixed appliances.

More research is needed that accounts for the various variables of a complex, multifactorial issue, namely age, nature of correction (skeletal vs. dentoalveolar), residual maxillary growth, and mandibular growth. The Cochrane database systematic review remains at the level of a protocol (Harrison et al. 2002).

The Difficulty of Forecasting Growth and the Dilemma of Overcorrection

The major problem with early treatment of mesiocclusion with underlying skeletal discrepancy is the inability to precisely forecast its development. The orthodontist tries to anticipate the growth spurt to minimize its effect (e.g., favoring maxillary growth or mandibular rotation to counteract additional mandibular growth). Unlike Class II malocclusions, in which mandibular growth helps treatment, further mandibular growth in Class III is not balanced by concomitant maxillary growth. The maxilla grows at a slower rate than the mandible and ceases forward growth nearly 2 years before the mandible (Cortella, Shofer & Ghafari 1997).

The combination of maxillary expansion and face mask is advocated with overcorrection, i.e., increase of overjet, which results from both the maxillary protraction (with a

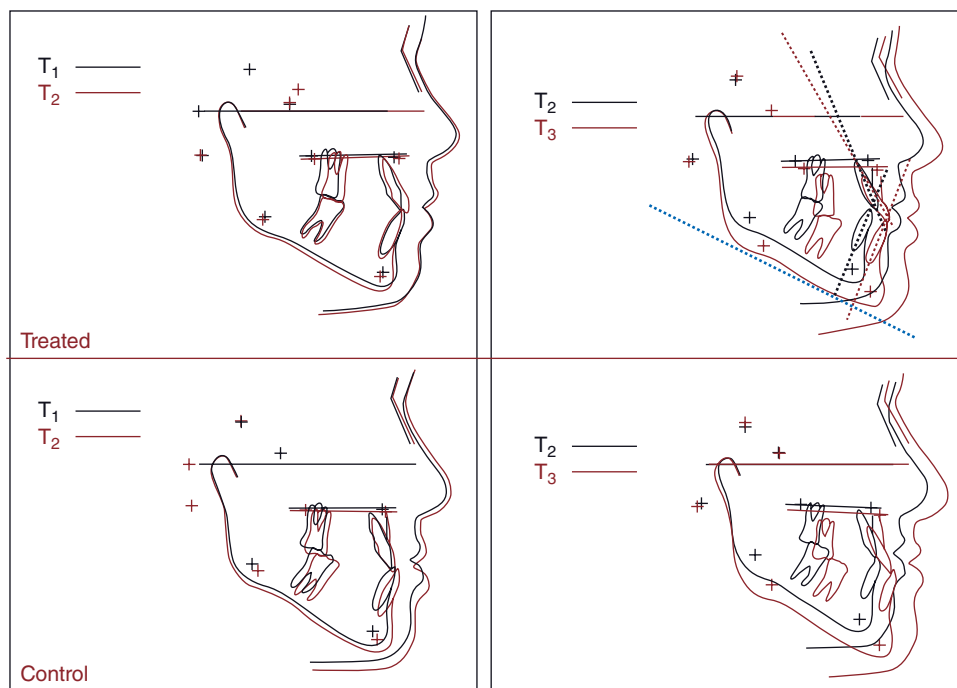


Figure 16.9 Top row: Changes from superimposed cephalographs of treated patients between baseline (T1) and end of phase 1 (T2) (10 months), and between T2 and post-treatment (T3) (5 years, 7 months). Bottom row: Superimposition of cephalographs of matched control subjects at corresponding observation periods, T1–T2 (14 months) and T2–T3 (6 years). Adapted from Westwood et al. (2003).

side effect of counterclockwise rotation) and mandibular clockwise rotation (Figure 16.10). Given the inaccuracy of growth forecasting, the amount of overjet overcorrection cannot be determined precisely, leading to one of these possibilities:

1. Mandibular forward growth equals the amount of overcorrection; then, the present compensatory incisor angulations are maintained; or
2. The mandible grows less than the amount of overcorrection; thus the mandibular incisors are proclined for the residual overjet correction.

In addition, the results must be retained and reevaluated throughout the period of growth, leading to longer treatment, particularly if started in the primary dentition and revisited in the mixed and later the permanent dentitions.

Class III malocclusions with prognathic, particularly macrognathic mandibles often require a surgical correction that is delayed until after or toward the end of mandibular growth (skeletal ages of 16–18 years in females, 18–20 years in males). Yet, early treatment may reduce the severity of the malocclusion by minimizing associated problems such as crowding of the maxillary arch. Left uncorrected, this problem may require later tooth

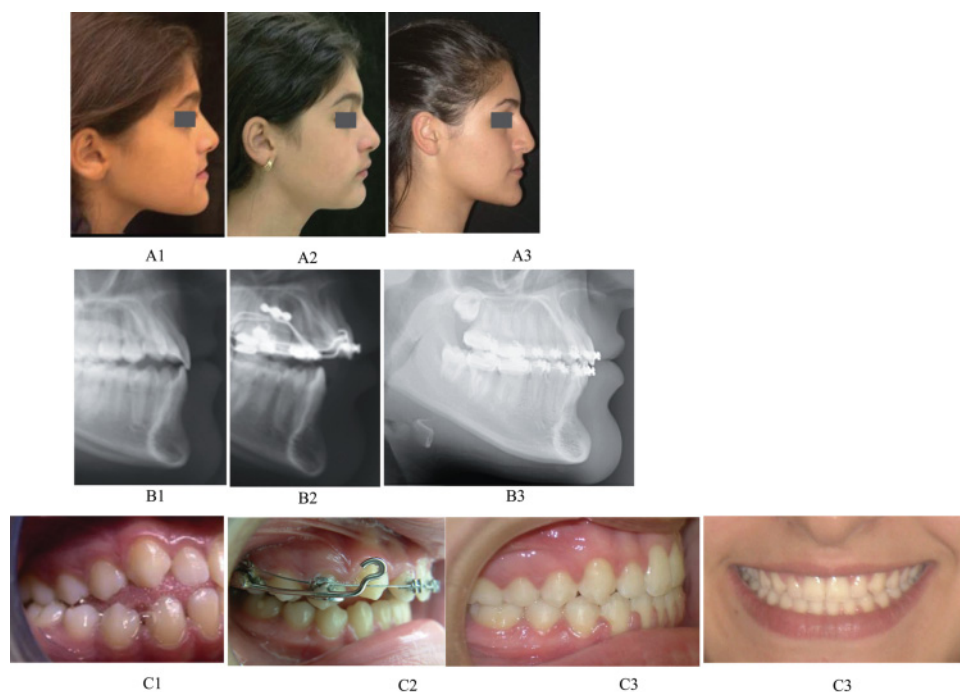


Figure 16.10 Profile photographs (A1–A3), lateral cephalographs (B1–B3), and occlusal views (C1–C3) of female 10 years, 9 months old, who was treated with maxillary expansion and protraction face mask in phase 1 to an overcorrected overjet. The records were taken at pretreatment (A1, B1, C1), 6 months (A2, B2, C2), and 6 years (A3, B3, C3) from treatment start. After an extended period of retention that lasted beyond the adolescent growth spurt, fixed appliances were used to achieve the well-interdigitated neutroclusion (C3). The overcorrection was performed to anticipate either mandibular growth equal to the amount of overcorrection, in which instance pretreatment mandibular incisor angulations would have been maintained, or mandibular growth less than the amount of overcorrection, in which instance the mandibular incisors would be proclined for the remainder of overjet correction. The actual outcome was a “middle” situation: the mandibular incisors ended up more proclined than pretreatment, and the facial profile more orthognathic than the original concave outline. Although the treatment avoided orthognathic surgery, it lasted a long time because appliances were kept beyond a late-occurring adolescent growth spurt. Note improvement (reversal of steps) in relation between upper and lower lips.

extractions (usually premolars) that contract the maxillary arch, possibly necessitating maxillary surgical widening.

In many instances, parents pressure the orthodontist to start early correction of a noticeable mesiocclusion. Early treatment becomes questionable when the patient ends up undergoing surgery at an older age. All the diagnostic and therapeutic components must be weighed carefully in the individual patient. Research should determine valid long-term options.

Adult Treatment

Orthodontic Options

Randomized studies are not available for nonsurgical (camouflage) treatment of mesiocclusion with skeletal discrepancy in nongrowing or adult patients. However, case reports indicate that surgery may be avoided with a combination of mandibular rotation and compensatory inclination of teeth over basal bones. To this basic rationale may be added the extraction of premolars for further incisor retroclination or the distal movement of mandibular molars, possibly requiring the extraction of third molars, followed by the retraction of the more anterior teeth (Figure 16.11). This approach contributes to the correction of posterior transverse maxillary-mandibular relations.

Interestingly, the concern about bite opening is not fully justified. Klontz (2006) indicated in the context of open bite correction that third molar extraction helps control arch expansion and anchorage preparation (around the second molars). Extraction of the often impacted mandibular third molars is increasingly performed at earlier ages (unlike the riskier early extraction of maxillary third molars), because it requires less extensive surgery (of more developed roots), inducing less morbidity. Orthodontic implants increasingly represent an auxiliary that helps retract teeth in the buccal and anterior segments.

In specific “mild” Class III malocclusions, particularly when coupled with “large mandibular intercanine width,” minor crowding, and “some” mandibular tooth size excess, the extraction of one mandibular incisor was deemed satisfactory, although treatment in the 36 adults studied “became more complicated and time-consuming than expected” (Faerovig & Zachrisson 1999).

In a comparative study of Class III patients treated with either surgery or camouflage, the pretreatment records showed significantly more retroclined mandibular incisors, more protrusive mandible, and more severe skeletal discrepancy in the surgery group (Troy et al. 2009). At posttreatment (which probably occurred earlier in the orthodontic group, though both groups were past their “growth spurt”), differences in mandibular incisor inclination between the two groups were not statistically significant, confirming that the surgery group finished treatment with compensated incisors and a mild Class III skeletal discrepancy, similar to the camouflage group. This study indicates that (a) the more severe mesiocclusions need surgical treatment and (b) that improper normalization (decompensation) of mandibular incisor inclination over basal bone leads to compromised surgical movement of the bones, the final outcome of treatment approaching the nonorthodontic pretreatment skeletal measurements with ensuing compensation of the incisors that resembled their compensation without surgery.

In a discriminant analysis, Stellzig-Eisenhauer, Lux & Schuster (2002) found the Wits appraisal most decisive in distinguishing camouflage treatment from surgical treatment. An appraisal greater than -5 mm indicates that the malocclusion might not be resolved by camouflage. Long-term studies on stability, periodontal health, and patient satisfaction are needed.

The use of a face mask in adults has been reported in conjunction with surgically assisted rapid palatal expansion (SARPE) (Pelo et al. 2007). The question arises regarding the significance and practicality of SARPE rather than a maxillary Lefort 1 osteotomy combining maxillary advancement and widening if needed (Figure 16.7). The latter surgery is presumably longer and more morbid, but using the Delaire mask requires predictable compliance and ideally the certainty that mandibular surgery is not indicated.

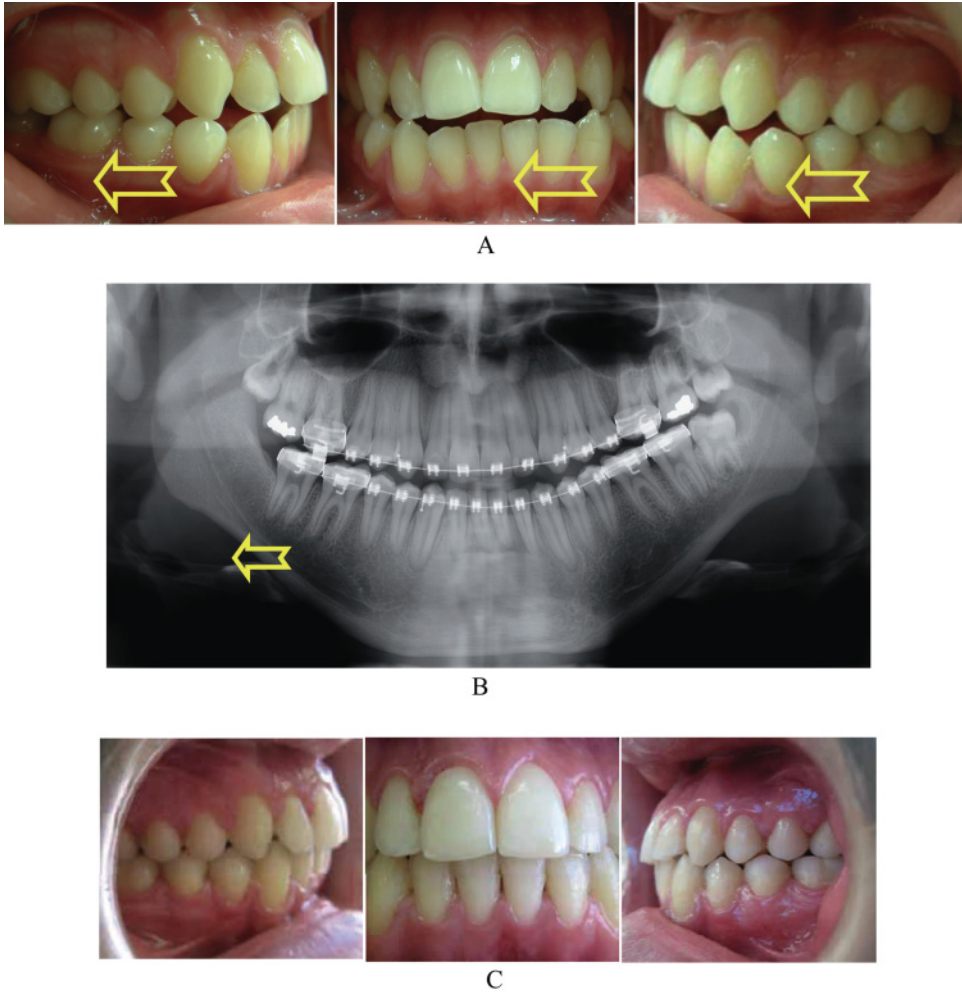


Figure 16.11 (A) Pretreatment occlusion of male 16 years, 1 month old with mesiocclusion of molars and canines, fitting Angle's description of Class III, division 1 subdivision. The treatment plan included the extraction of the right third molar, distalization of the mandibular teeth on the same side leading to the alignment of the midlines (arrows). (B) Panoramic taken 2 months before removal of orthodontic appliances shows uprighted teeth mesial to extracted mandibular right third molar. (C) Posttreatment occlusion.

Otherwise, maxillary and mandibular osteotomies would be performed during the same operation.

Combined Orthodontics and Orthognathic Surgery

Maxillary advancement has changed roles with mandibular setback because maxillary surgery produces both more aesthetic and more stable results (Proffit, Turvey & Phillips 1996). This development is compatible with the finding that maxillary retrognathism is

more prevalent than previously thought (see General Characteristics above). To illustrate the variation in surgical goals, two patients with mandibular prognathism are presented with different treatment approaches that combined the best available evidence, with prudent clinical judgment to answer the patients' concerns.

Lower-Face Aesthetics Dictates Maxillary Surgery Only The chief complaint of a 30-year-old male was anterior crossbite and mandibular prognathism, also found in other members of his family. Cephalometric evaluation supported the diagnosis of mandibular macrognathia and prognathism (Figure 16.12). However, in assessing the esthetics of the lower face, the obtuse relation between chin and throat favored more maxillary advancement than mandibular setback.

Patient Complaint Favors Mandibular Surgery Treatment of a Class III malocclusion associated with anterior open bite (Figure 16.13), maxillary retrognathism, and mandibular prognathism could have been limited to maxillary surgical clockwise rotation (anterior part down). However, the patient requested reduction of a “long” mandible. Consequently, surgery included maxillary rotation and downward movement (for optimal incisor display during smile), mandibular setback (4 mm) and genioplasty (length reduction by 2 mm).

In both patients, besides functional rehabilitation, the aesthetic issues were primary in setting and implementing the treatment. In addition to following the “best” evidence on technical execution of the surgeries, in approach, and in rigid fixation, evidence on stability of results was respected. Maxillary surgery is reported to be more stable than mandibular setback (Proffit, Turvey & Phillips 1996). This finding was followed in the first malocclusion (Figure 16.11). Although mandibular setback in the second patient (Figure 16.12) answered the chief complaint of an elongated mandible, it did not affect chin projection because the reduction compensated for the anterior mandibular projection following the autorotation that resulted from posterior maxillary impaction.

Evidence-based Treatment of Class III Malocclusion

Incorporating Evidence Search in Individual Decision Making

Defining the Evidence

Evidence-based practice (EBP), which “integrates individual clinical expertise with the best available external clinical evidence from systematic research” (Sackett et al. 1991, 1996), is a problem-oriented approach to decision making. The combination of best available evidence with judgment underlines the need to stratify a voluminous amount of information entering the stream of medicine daily and to use reason to logically apply the evidence in individual patients. Organized and graded according to specific guidelines, the hierarchy of evidence ranges from the least to more rigorous scientific evidence, commonly ordered up from expert opinion to case report, case series, case-control study, cohort study, randomized controlled trial (RCT, the gold standard of studies), and systematic review/meta-analysis (Woolf et al. 1990; Oxman, Sackett & Guyatt 1993; Greenhalgh 1997). Ghafari et al. (2007b) and Ghafari, Souccar & Saadeh (2008) categorized this hierarchy into three levels, ascending from perspective (analysis and opinion), to investigation (all types of studies, classified on research design), to synthesis (reviews and meta-analysis).

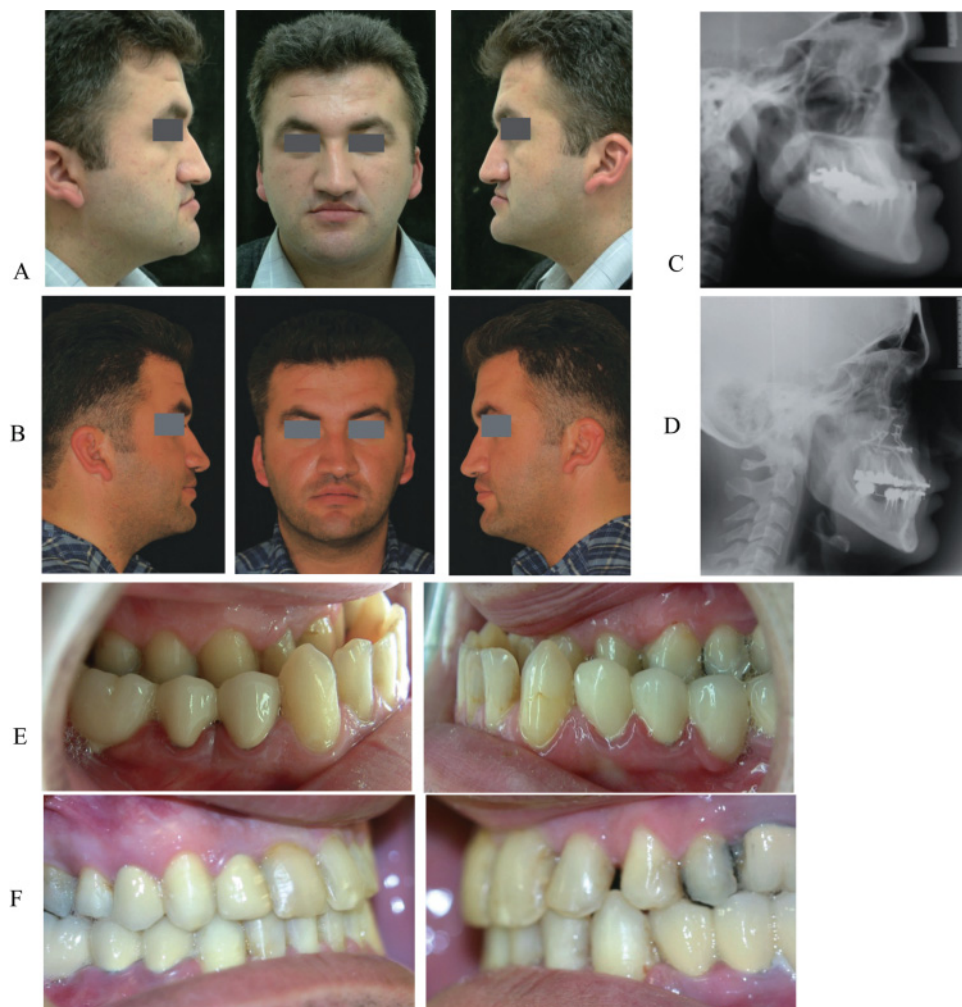


Figure 16.12 Pretreatment (A, C, E) and posttreatment (B, D, F) profiles, cephalographs, and occlusal views of man 30 years, 7 months old whose Class III malocclusion was treated with a combination of orthodontics and orthognathic surgery. X-ray reveals mandibular macrognathia and prognathism (C). Maxillary arch was entirely embedded within mandibular arch (E). Because of obtuse chin-throat angle (A), surgery was limited to maxillary advancement (8mm) and downward movement (4mm). Posttreatment profile (B), pre-debanding cephalograph (D), and posttreatment occlusion (F) reflect correction to Class I occlusion. Subsequent dental work was to include change of existing prostheses and aesthetic restoration of incisors.



Figure 16.13 This 20-year, 1-month-old patient's Class III malocclusion was associated with anterior open bite, maxillary retrognathism, and mandibular prognathism. She also complained of a "long" mandible. Treatment consisted of maxillary LeFort I osteotomy with clockwise rotation to improve the smile aesthetic line for additional incisor display upon smile. The maxillary movement limited mandibular setback to 4 mm. A genioplasty of 2 mm further reduced mandibular length. (A, B) Profiles before treatment and posttreatment (2.5 years later). (C) Tracings indicating the change (green) from presurgical cephalogram (black). (D, E) Pre- and posttreatment occlusal photographs.

As EBP draws on scientific evidence, the clinician's personal experience, and the patient's individual values, finding the valid, current, and relevant evidence involves a well-defined process that helps identify and use online resources to support decision making on specific clinical questions and requires appropriate skills to formulate clear questions, carry out efficient searches, and critically appraise the literature before implementing treatment. The PICO (patient intervention comparison outcome) represents a widely used strategy to construct the research question and search the evidence that could be applied to the specific orthodontic problem.

Table 16.1 Description of the PICO process.

Patient/population	How would you describe your patient or population? What characteristics of your patient/s are important (age, gender, condition, etc.)?
Intervention	What intervention or indicator are you interested in (therapy, diagnostic test, or exposure)?
Comparator/control	What alternative or different option do you want to compare your intervention to (compare to another intervention or to no intervention)?
Outcome	What measurable outcome/s are you interested in?

The Process: PICO to Treatment Selection

Turning a clinical problem into an answerable question is a key step in EBP. The broad, complex, and multilevel questions pertaining to Class III need to be refined and narrowed to answerable inquiries when searching the literature. To underscore the procedural difficulty in searching databases for the “best treatment for skeletal Class III malocclusion,” a search for “Class III malocclusion” alone in PubMed would retrieve 2237 records (as of November 2009). As the search for words such as “best” is not feasible, we would search the pertinent issues, treatment timing, and treatment modality to limit the number of records retrieved.

The PICO framework is used for this purpose. PICO stands for patient (or population) intervention (or indicator) comparison (or control) outcome (Table 16.1).

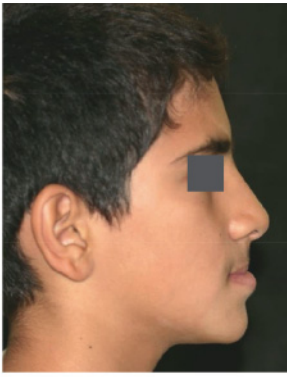
The aims are to *get* the question clear in mind, *identify* the information needed to answer the question, *translate* the question into searchable terms, and *develop* and *refine* the search approach

Application to a Specific Malocclusion

Clinical Question

The process is applied retrospectively to a boy 12 years, 3 months old seeking treatment for severe “underbite.” His Class III malocclusion was characterized with maxillary retrognathism and maxillary prognathism (Figure 16.14). The clinical question was as follows: What is the “best” treatment modality for him? To answer the question, the PICO method was used (Table 16.2).

Essentially, we asked the question on modality: Should treatment be delayed in favor of combined orthodontics and orthognathic surgery? Another obvious question would have focused on treatment timing: What is the merit of orthopedic/orthodontic treatment at the age of 13 years? The corresponding PICO formulation would have been the following: In growing patients (P), how does treatment closer to the growth spurt (I), compared with early treatment in midchildhood (C), affect skeletal sagittal relationship (O)? A close evaluation of this question would reveal the similarity to the first question in terms of gauging the available best evidence. Indeed, with either formulation, the search would



A



B



C



D



E



F



G



H



I



J



K

Figure 16.14 Records of boy 12 years, 3 months old treated for Class III malocclusion with a combination of palatal expansion-face mask, fixed appliances, and Class 3 elastics between dental arches and for a period of 6 months against temporary anchorage devices implanted at the level of the mandibular canines. Profile views include photographs taken at pretreatment (A), 17 months (B), and 4 years 2 months (C) after initiation of therapy. At this time, appliances and Class 3 mechanics are maintained because growth had not ceased. In comparison to initial occlusal views (D), neutroclusion had been maintained (E). The anterior crossbite was corrected from -7.5 mm to 4.5 mm in the first 17.5 months but later settled at 3 mm. Serial cephalographs starting with pretreatment record (F–K) illustrate treatment progress at the time intervals indicated. Patient compliance was exemplary.



Table 16.2 Application of the PICO method to the patient in Figure 16.14.

In	growing patients	(<i>P</i> component)
How does	orthopedic treatment	(<i>I</i> component)
Compared with	delayed surgical treatment	(<i>C</i> component)
Affect	skeletal sagittal relationship	(<i>O</i> component)

have to center on successful treatment in late childhood and thus the decision on whether intervention at this age would yield orthopedic and orthodontic changes that would avoid surgery after growth has ceased and, if the evidence is available, might even be equal to or better than surgery in adulthood.

Available Evidence

Timing of Treatment in Growing Patients: Earlier versus Later Intervention The debate on timing treatment in early or late childhood is traced back to Angle (1907) who advocated early treatment “as near the beginning of the variation from the normal in the process of the development of the dental apparatus as possible,” opposing the argument of the “old school that this is a most unpromising age for treatment,” mostly because of cooperation.

The balance of investigations at the higher levels of evidence points to the advantage of treatment at a younger age for greater orthopedic change (Franchi, Baccetti & McNamara 1998; Kapust, Sinclair & Turley 1998; Kim et al. 1999; Suda et al. 2000; Yuksel, Ucem & Keykubat 2001), but lower level evidence (cohort and case studies) indicates that treatment outcome was not related to timing of therapy (Baik 1995; Sung & Baik 1998; Merwin et al. 1997). The difference may be in specific responses at various layers of the question. Although correction is achieved faster and with less cooperation (hours of appliance wear per day) in younger children in the primary and early mixed dentitions (Saadia & Torres 2000), orthopedic changes are indeed obtained in the 10- to 14-year age group (Turley 2002).

Therefore, in this prepubertal patient (bone and chronological ages coincide), orthopedic changes are possible, but the amount is unpredictable, most likely dependent on inherent genetic component and level of compliance.

Growth Events Advantage is taken of opportunities that normal growth provides at specific landmarks: the time of loss of the primary second molar (E) to avoid loss of leeway space (Ghafari 2007) and the adolescent growth spurt, as the increased rate of mandibular growth would worsen the Class III relationship or cause relapse of a previous correction, absent the benefit of overcorrection that anticipates the added growth.

Optimal treatment time would be in the late mixed dentition, or the early permanent dentition if preservation of the leeway space is not needed (Ghafari 1999). Treatment closer to the time of onset of the adolescent growth, particularly in girls, would combine the advantages of dental development and maxillary protraction (to overcome increased mandibular skeletal growth) in a period of 2 years, the average orthodontic treatment time. This practicality does not apply (on average) to boys because of the longer intermediate span between the loss of the Es and onset of the growth spurt (Ghafari et al. 1998a, Ghafari 1998b, 1999).

Therefore, in this male patient, bridging the severe anterior crossbite (7.5 mm) and needing significant overjet overcorrection to anticipate additional mandibular growth are ambitious goals that would favor the prospect of later orthognathic surgery. Yet, maxillary expansion is feasible at his prepubertal age. The dentition is permanent, thus consideration of leeway space is irrelevant.

Choice of Treatment

Based on the assessed literature, orthodontic treatment would be most successful

1. in *younger children*;
2. using a *face mask*, possibly with maxillary expansion, presumably to decrease the resistance of buttressing bones (absent a posterior crossbite, maxillary expansion is actually not needed for transverse occlusal correction); and
3. *overtreating* to an overjet greater than normal.

Our patient already had a full permanent dentition but was still prepubertal, an indicator of potential worsening of the malocclusion.

A treatment plan for later orthognathic surgery was presented to the parents. Alternative orthodontic approaches including extraction of mandibular premolars or third molars to retrocline the mandibular incisors for further compensation were not deemed viable given the already upright position of the incisors. The parents were informed that the anterior crossbite of 7.5 mm and underlying severe skeletal discrepancy (ANB = -7 degrees, norm 2 degrees) were difficult if not impossible to overcome with orthodontic treatment alone. Nevertheless, they wished to try the nonsurgical approach. The child was extremely motivated and compliant.

Treatment Progress

Treatment started with maxillary expansion, followed 1 week later with reverse headgear. Compliance was exemplary (reaching nearly 20 hours per day), witness the chin irritation from prolonged wear that required treatment with local ointment and temporary suspension of wear. Nearly 1.5 years after treatment initiation, the overjet was overcorrected to $+4.5$ mm, and facial appearance greatly improved to an attractive profile (Figure 16.14). When cooperation was relaxed to less face mask wear, because the patient was to wear

class 3 elastics to temporary anchorage devices placed in the mandibular canine regions, overjet relapsed to 3 mm, coinciding with a period of increased growth and requiring resumption of face mask treatment.

Growth was monitored through annual hand-wrist x-rays and maxillofacial outcome gauged with cephalometric superimpositions. Nearly 4 years after start of treatment, correction was maintained, not because of a major singular change but rather because of the combination of maxillary protraction, mandibular rotation, and incisor compensation that together overcame the original malocclusion and the additional mandibular growth (see Component Analysis, below). With bone age nearly 17 years, orthognathic surgery might not be required.

Perspective on the Scope of Evidence

Widening the Scope of Evidence

Assessing treatment success in the above patient (Figure 16.14) in view of PICO-generated findings, several potential hypotheses emerge that should be investigated.

Compliance

Sustained compliance may be crucial for success of growth modification. The premise to test is whether additional compliance over growth period may lead to greater expression of growth potential, at least in the older patients (late mixed dentition or early permanent dentition, still prepubertal period).

Treatment Timing and Duration

Although the evidence suggests that treatment should start at a younger age in the mixed dentition, treatment of a severe mesiocclusion before the pubertal growth spurt was achievable with sustained compliance, suggesting that early orthodontic treatment should not be overdone. While dealing with growth changes should not be missed (Ghafari 1999, 2007), keeping up with these changes, which are also related to existing neuromuscular patterns, lengthens the treatment, with the potential consequences of decreased compliance and increased side effects (root resorption, potential caries, and periodontal problems).

One specific question yet to be answered is whether treatment in early childhood rather than in the late mixed dentition engenders greater amounts of maxillary basal bone advancement concomitant with less compensatory proclination of maxillary incisors and more stable results. One of the outcome measures should be the aesthetic, not only dental and bony, changes.

Regardless of when treatment is started, success may not be achieved if treatment is not maintained for long periods of time during growth (Figure 16.14), albeit including periods of retention between spans of more active treatment. Long-term compliance is not obtained in most children because of the commonly reported “burn-out.” Yet, the following question needs investigation: Is treatment duration (long term) more important than timing?

Objective Conditions for Intervention and Research

Specific criteria or conditions should be defined that would require either earlier treatment, for example, severe anterior crossbite associated with psychological conditions (Ghafari et al. 1998a; Tung & Kiyak 1998; Ghafari 2007), removal of primary etiological factors such as enlarged adenoids and/or tonsils forcing forward positioning, as suggested by Angle (1907), or later treatment, with the possibility of stable correction.

In this context, two important questions require investigation: (1) is midface deficiency (maxillary retrognathism) the defining characteristic for early intervention and stable results? and (2) if mandibular thrust in an anterior crossbite induces maxillary retrognathism, is it possible that it may also stimulate mandibular growth and worsen the mesioclusion? Research on nasopharyngeal obstruction by enlarged adenoids revealed important insight on the interaction between the growing jaws. Apparently independent from its direct effect on the mandible, nasal obstruction affects maxillary morphology, which in turn impacts on mandibular size (Macari 2008).

One of our general observations in the combined palatal expansion-face mask approach is that maximal response occurs in the first 3 to 4 weeks after the face mask is delivered (usually 1 week following the expansion). Consequently, patient compliance is critical and must be emphasized (along with the achievement of overcorrection) in these first weeks of treatment.

If this premise is true, it implies that maxillary resistance to movement by the expansion determines the maximal response. When the expansion is not needed to correct the transverse occlusal relations, patients may be instructed to alternate opening and closing the expansion screw. These regimens should be investigated, particularly in view of the evidence that although face mask therapy with or without palatal expansion produced equivalent changes (Vaughn et al. 2005), treatment with nonexpansion was longer (Kim et al. 1999). The benefit of expansion may indeed be the potential for increased response in less time.

Limiting the testing of the above questions is the long-term nature of investigation, the needed large numbers of patients, and the difficulty of randomization under such conditions. Establishing multicenter registries might provide an acceptable and credible alternative.

Minimizing Side Effects

Maxillary anatomy represents a limitation to protraction and favors a downward posterior (counterclockwise) rotation of the maxillary bone and occlusion. For successful forward movement of the maxilla, the forces must be applied at the level of its center of resistance (CR), which would require a higher pull that interferes with the upper lip. The inability to direct the forces through the CR engenders the often unwanted rotation (Figure 16.15).

To remedy this situation, modified designs have been advocated (Toros, Keles & Erverdi 2000; Keles et al. 2002), such as a regular headgear with its inner bow attached at the level of the first molars extending outside the lips, and its outer bow bent up to the level of the maxillary CR providing the higher level of force application (Stockli & Teuscher 1985).

Another solution is to pull the forces against implants embedded in the maxillary bone. The use of implanted zygomatic and mandibular plates along with Class 3 elastics (De

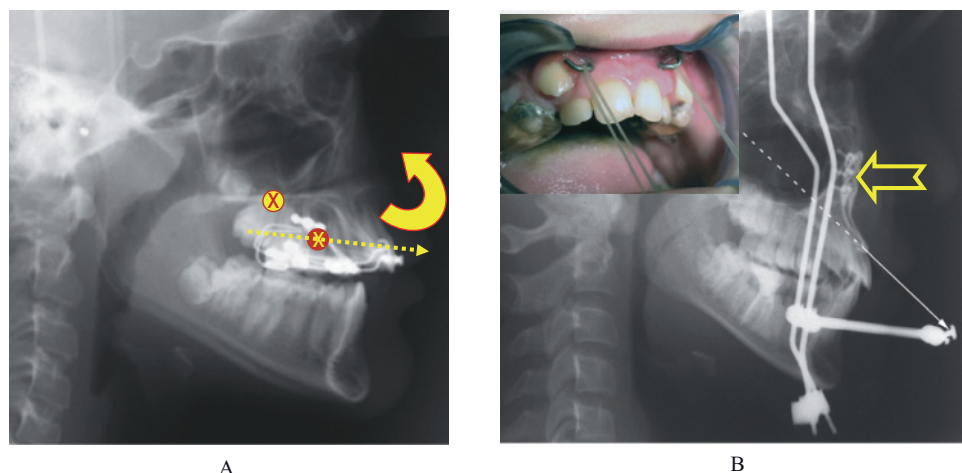


Figure 16.15 (A) Record of patient in Figure 16.10 illustrates the different location of the centers of resistance of first molar (actually the center of resistance of the “group” of first molars and premolars splinted in the palatal expander—red circle) and maxilla (yellow circle) that leads to contradictory rotations. Anterior force at the level of the molar (or splinted teeth) center of resistance has as side effect a counterclockwise movement to the protracting force (straight dashed yellow arrow) that leads to an upward rotation (curved yellow arrow) of the palatal and occlusal planes because the protracting force direction is below the center of resistance of the maxilla. Directing the force along this center through an implant positioned in its line may lead to less rotation (if such rotation is not planned). (B) Application of pull through plates implanted anteriorly. (Adapted from Kircelli & Pektas 2008.)

Clerk et al. 2009) or face mask against miniplates at the lateral nasal walls of the maxilla on both sides of the apertura piriformis (Kircelli & Pektas 2008) (Figure 16.15) has been reported to be successful, but it requires surgical steps for placement and removal of the plates. Using orthodontic implants (temporary anchorage devices) without surgery is an alternative that warrants research, as authors have reported successful face mask pull against ankylosed primary teeth (Kokich 1985; Omnell & Sheller 1994). Randomized clinical trials may be conducted with various implant alternatives.

Interaction Between Overcorrection of Maxillary Protraction, Maxillary Incisor Inclination, and Spacing Within the Arch

One of the major advantages of overcorrection through maxillary protraction is the possibility of *normalizing incisal inclinations*. The implication is the need for additional space in the maxillary arch to retrocline the incisors, underlining the importance of saving the leeway space. If this space is not adequate for moving the incisors backward, a contradictory situation evolves: the necessity of distalizing maxillary posterior teeth without affecting the protracted maxillary bone. Sequential distalization of molars, then premolars and canines individually, is the safest approach. Proclination of retruded mandibular incisors creates space within the arch but should not be undertaken before fuller

expression of mandibular growth (see as discussed earlier). Research has not addressed this interaction.

Another corollary premise that also should be investigated is the possibility of maxillary incisor decompensation if treatment is started earlier (primary or early mixed dentition; see Figure 16.8) and the persistence of maxillary incisal compensation in older patients (Figure 16.14).

Component Analysis

The expectation that one major factor or event should explain the outcome of treatment or growth does not reflect reality. Instead, the various components of the hard tissues underlying the soft tissue envelope contribute to the outcome. Efstratiadis et al. (2005) referred to the cumulative effects of several regional, small to moderate changes that accounted for the successful treatment of Class II malocclusion, including incisor compensation, mandibular rotation, and both vertical and backward maxillary movement. Other component analyses apply to facial aesthetics, to the aforementioned interaction between the jaws following nasal obstruction, and to the development and treatment of Class III malocclusion, albeit in individual malocclusions dominance of a specific feature may exist. Research should focus on the contribution of different components in various degrees of association to achievement and perhaps prediction of the outcome.

Component analysis relies on available imaging tools, so far mostly depending on cephalometric measurements, which still need standardization and lack systematic evaluation of profile changes, including the variable soft tissue thickness. The soft tissue drape may exacerbate or mask the underlying hard tissue structures. Technological advances in radiography bring the goal of 3-D study of the face and dentition within reach (Ghafari 1997, 2006). This objective would still require the assessment of both angular-linear measurements and regional superimpositions (Figure 16.16) to fully understand facial changes (Ghafari, Baumrind & Efstratiadis 1998c; Efstratiadis et al. 2005).

Predictability of Results

Although several characteristics emerge from clinical studies as being essential in developing prediction models (Ghafari, Baumrind & Efstratiadis 1998c), the difficulty in this task is discovering and characterizing the sources of individual variations (Baumrind 1995). The variables in a Class III prediction model would include, where applicable, the amount of anterior crossbite, alone or in conjunction with the molar or canine relationship; maxillary incisor inclination; maxillary and mandibular position and size; compliance; and information on general growth to assess the impact of additional growth on malocclusion and treatment.

Prediction models have been explored to estimate an individual's mandibular growth curve from serial measurements of stature (Buschang & Demirjian 1993). Presumably, such models would be more successful as additional longitudinal data on skeletal (body height and/or bone age) and craniofacial parameters are incorporated in the model. It is hoped that more standards of somatic growth would be available, such as measures of hormones and enzymes (Ghafari et al. 1995). The incorporation of all such data should allow individual prediction models to be developed and tested for accuracy under conditions of normal growth and/or orthodontic treatment.

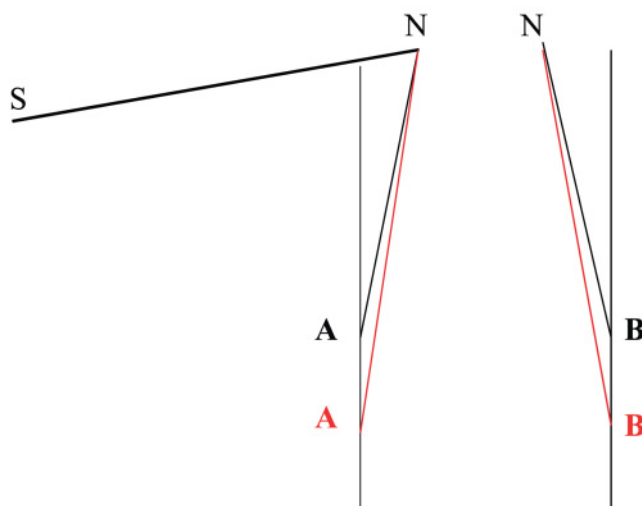


Figure 16.16 Angular and linear measurements provide information that combines the vertical and sagittal components reflecting the displacement of a landmark and its associated structures. An increase in the SNA angle following orthodontic treatment with a face mask demonstrates protraction of a retrognathic maxilla relative to nasion, an important assessment to depict a change closely related to the facial profile. Upon superimposition on the anterior cranial base, however, the vertical movement of point A may be the prevalent displacement, which would still account for the increase in the SNA angle (left). The opposite is true for point B and the SNB angle (right), as a downward movement of point B leads to a decrease of SNB if the mandible is prognathic but not if it is orthognathic or retrognathic. The superposition allows the evaluation of the displacement in its vertical and sagittal components separately, relative to a central-anterior cranial structure that is relatively more stable than nasion.

Reality of Evidence-based Treatment: Between Neglect and Acceptance

Evidence-based practice has permeated all medical fields and stirred arguments for or against the trend that range from negating the value of any treatment without high evidence to attacking the evidence ladder as “dangerous innovation” or caricaturing meta-analysis as “shmeta-analysis” (Shapiro 1994). Most clinicians seek to buttress their treatment with available evidence but may question the practicality of even upper-tier scientific evidence when it does not support specific regimens successful in their experience (Gianelly 2006; Ackerman, Kean & Ackerman 2006). One example is the use of palatal expansion with maxillary protraction, when research shows no difference in results when the palate is not expanded.

Many variables can be cited to illustrate the neglect of evidence even by proponents of EB orthodontics. Existing clinical guidelines offer at best central tendencies confounded by the level of patient compliance. Other reasons include the following:

1. Individual factors such as ill-defined variations around the average outcomes, the possibility of individual response to lie outside prevailing central tendencies,

and constitutional limitations (specific deviant morphology such as an elongated chin that maintains facial concavity despite occlusal correction)

2. The unpredictability of individual controlling factors, namely compliance and growth
3. Availability of compromised treatment approaches to address limited objectives or reduce treatment time (leeway of choices)
4. Existence of borderline conditions amenable to alternative treatment options. Such conditions include a mesiocclusion that could be corrected orthodontically or surgically, or a compensated skeletal discrepancy that may be treated (Figure 16.17) or observed for later treatment
5. Relatively benign side effects of the “average” orthodontic treatment (root resorption, limited and often retreatable relapse, long treatment) and lack of support for rare and more painful consequences (temporomandibular dysfunction)
6. Prevalence of aesthetics awareness, sometimes at the expense of the evidence available for occlusal stability, counteracting the negative impact of decades of the “dished-in” profile that plagued the profession as the “orthodontic look,” resulting from the prevalence of extraction of (mostly) premolars to resolve malocclusions
7. Potential for present evidence to be different in future research (Ioannidis 2005), particularly with the improvement in research tools. Although recognized as the gold standard in research, the RCT may be limited on ethical grounds for comparison of certain irreversible treatment strategies (extraction vs. nonextraction, orthognathic surgery vs. orthodontic treatment). On the other hand, lower level evidence is appropriate to answer certain questions (e.g. loss of E space), forgoing the need for RCTs.
8. The possibility that technological developments may shift treatment paradigms in directions that make recent research questions benign or even obsolete. Temporary implants for anchorage (miniscrews or plates) have resolved issues of anchorage that earlier required different mechanical setups and patient compliance. The impact of tissue engineering on periodontics and orthodontics reflects on treatment goals and modalities, as well as mechanotherapy.

In reality, the evidence may never be totally neglected because tracks of knowledge are available with various levels of evidence. In complex malocclusions (e.g., Class III with open bite), layers of evidence are present for separate components of the malocclusion (sagittal Class III, or open bite), even though the complexity of such malocclusions is not the specific target of existing investigations (coexisting Class III and open bite). Existing evidence is probably applied at least at some layers of a multilayered malocclusion. This very practice supports randomized treatment in research (with proper selection criteria), because randomization should eliminate the bias of both known and unknown variables

Almost every systematic review on Class III malocclusion ends with the statement of need for “more high-quality clinical research.” Many studies require repetition with stricter methodology. A priori rejection or blind adherence to the evidence ladder is not a sound

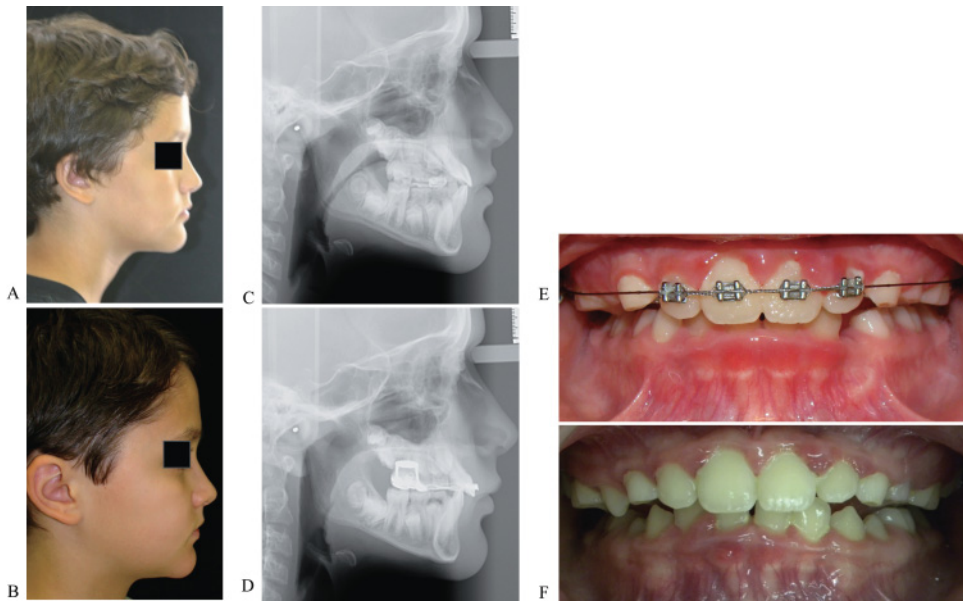


Figure 16.17 Corresponding sets of facial profile and lateral cephalograph at pretreatment (A, C) and post-phase 1 of treatment (B, D) of boy whose treatment started at age 11 years, 2 months, with palatal expansion-face mask protraction combination. Only the maxillary incisors were aligned with fixed appliances (E). Although the initial occlusion exhibited positive overjet, the skeletal relation between the jaws displayed a tendency to Class III ($ANB = -1.2$ degrees), with a retrognathic maxilla compensated with proclined maxillary incisors (C) underlying a flat midface (A). Extensive compliance led to thinning of gingiva below mandibular incisors because of pressure from the chin cap. Note improvement in midface appearance, improved relation between jaws ($ANB = +1.5$ degrees), and overcorrected overjet (D–F), which will allow retroclination of maxillary incisors in the later period of treatment if mandibular growth is proportionate to that of the maxilla. Treatment lasted 8 months, followed by retention with removable appliance. Given the absence of research on conditions such as this malocclusion, which may be qualified as borderline, another option would have been to wait until further growth occurred. The rationale for intervention, based on extrapolation from studies on treatment of Class III malocclusion with anterior crossbite, was to overcorrect the overjet, allowing potential decompensation of maxillary incisor proclination.

approach. Facing two opposing camps, the skeptic unwilling to accept the primacy of systematic research and review and the enthusiast lacking prudence to discern the substance from the process, Huang (2007) cautions against accepting any systematic review and meta-analysis as valid, stressing the responsibility of every clinician to understand the hierarchy of evidence, the principles of rigorous research, and the guidelines for proper conduct of systematic review. He sums up the charge of the health-care provider to be informed consumers of scientific information, with the basic goal of factoring out bias in research and systematic reviews.

Conclusion

The state of evidence regarding Class III malocclusion may be summarized as follows.

1. Mandibular prognathism is not the prevailing component of mesiocclusion; maxillary retrognathism is more severely deviant from the norm. If sustained, an anterior crossbite may cause maxillary retrognathism that otherwise would not exist. Treatment approaches necessarily vary with the diagnosis.
2. Evidence-based practice in Class III malocclusion is age dependent. Orthopedic correction is successful, more in milder skeletal discrepancies, faster in younger children, but unpredictable in the individual patient in terms of outcome and long-term stability.
3. Orthopedic schemes involve mainly a combination of maxillary protraction and mandibular clockwise rotation (except in the presence of open bite). Compliance, overjet overcorrection, and aggressive correction in the first weeks of treatment are important variables that need further investigation, particularly in their interaction with severity of malocclusion. Consequently, the clinician should evaluate the evidence and apply it on the basis of severity of malocclusion and best judgment on growth potential and compliance.
4. Research is sparse on mesiocclusion in the adult; orthognathic surgery is favored with severe skeletal dysplasias.
5. A mesiocclusion corrected at an early age may require later treatment during facial development. Early orthopedic correction of maxillary retrognathism may be overcome by lack of retention of the results (particularly if known etiology such as respiratory impairment persists) and/or mandibular growth favoring prognathism, though not necessarily macrognathism. Available research has not tackled these specific issues.
6. No evidence exists to demonstrate that orthopedic treatment on average corrects mesiocclusion to normocclusion without a level of compensatory inclination of maxillary and/or mandibular incisors. Longer-term treatment than investigated protocols, which would involve sustained but difficult to achieve compliance, may provide a different pool of knowledge.
7. Temporary anchorage devices may facilitate or speed up treatment, but the biological growth characteristics and etiologic elements do not promise drastically different timing or results of treatment. The orthopedic effect of various types of implants and biomechanical advantages need further exploration.
8. A number of limitations are associated with maxillary protraction: insufficient knowledge of underlying biological mechanisms limits potentiating the response to physical forces; maxillary anatomy engenders rotational side effects that might be resolved by using implants; difficulty in forecasting both the mandibular growth and the stability of maxillary orthopedics weakens prognostic accuracy.
9. The long-term and multivariable nature of orthodontic research, and type of evidence gathering, reduce the number of upper-level studies and consequently

reliance on EBP. Longitudinal research is needed but difficult to follow up over periods of 10 or more years.

While research sets central tendencies, individual variation favors interpretation of the evidence for more “effective, efficient, stable, and predictable treatment” (Huang 2004). Facing the range of viewpoints on EBP from support to rejection, the clinician should not indict the needed process of building and weighing the evidence but rather use judgment for a favorable application of the average response shown in investigations to the individual circumstances of patients.

References

- Ackerman, J., Kean, M. & Ackerman, M., 2006. Evidence-bolstered orthodontics. *Australian Orthodontic Journal* 22, pp. 69–70.
- Angle, E.H., 1907. Treatment—preliminary considerations. In: Angle, E.H., ed. *Malocclusion of the teeth*. 7th ed., Philadelphia: S.S. White Dental Manufacturing Co., pp. 309–313.
- Baccetti, T., Rey, D., Oberti, G. et al., 2009. Long-term outcomes of Class III treatment with mandibular cervical headgear followed by fixed appliances. *The Angle Orthodontist* 79, pp. 828–834.
- Baik, H.S., 1995. Clinical results of the maxillary protraction in Korean children. *American Journal of Orthodontics and Dentofacial Orthopedics* 108, pp. 583–592.
- Baumrind, S., 1995. The decision to extract: preliminary findings from a prospective clinical trial. In: McNamara, J.A., Jr., ed. *Orthodontic treatment: outcome and effectiveness*. Craniofacial Growth Series. Ann Arbor: Center for Growth and Development, University of Michigan, pp. 43–80.
- Brunelle, J.A., Bhat, M. & Lipton, J.A., 1996. Prevalence and distribution of selected occlusal characteristics in the U.S. population, 1988–1991. *Journal of Dental Research* 75, pp. 706–713.
- Buschang, P.H. & Demirjian, A., 1993. Modeling longitudinal statural and mandibular growth simultaneously. *Journal of Dental Research* 72, p. 366.
- Copray, J.C.V.M., Jansen, H.W.B. & Duterloo, H.S., 1985. Effects of compressive forces on proliferation and matrix synthesis in mandibular condylar cartilage of the rat in vitro. *Archives of Oral Biology* 30, pp. 299–304.
- Cortella, S., Shofer, F. & Ghafari, J., 1997. Transverse development of the jaws—norms for the posteroanterior cephalometric analysis. *American Journal of Orthodontics and Dentofacial Orthopedics* 112, pp. 519–522.
- De Clerck, H.J., Cornelis, M.A., Cevidanes, L.H. et al., 2009. Orthopedic traction of the maxilla with miniplates: a new perspective for treatment of midface deficiency. *Journal of Oral and Maxillofacial Surgery* 67, pp. 2123–2129.
- Delaire, J., 1980. Essai d’interprétation des principaux mécanismes liant la statique à la morphogénèse céphalique. *Actualités Odonto-stomatologiques* 130, pp. 189–220.
- Deshayes, M.J., 2006. Croissance crânienne et cinétiques osseuses interférant avec la morphogénèse faciale. Bases conceptuelles et réussites des traitements orthopédiques avant l’âge de 6 ans. *L’Orthodontie Française* 77, pp. 63–78.
- Efstratiadis, S., Baumrind, S., Shofer, F. et al., 2005. Evaluation of class II treatment by cephalometric regional superimpositions versus conventional measurements. *American Journal of Orthodontics and Dentofacial Orthopedics* 128, pp. 607–618.
- Faerovig, E. & Zachrisson, B.U., 1999. Effects of mandibular incisor extraction on anterior occlusion in adults with Class III malocclusion and reduced overbite. *American Journal of Orthodontics and Dentofacial Orthopedics* 115, pp. 113–124.
- Franchi, L., Baccetti, T., & McNamara, J.A., Jr., 1998. Shape-coordinate analysis of skeletal changes induced by rapid maxillary expansion and facial mask therapy. *American Journal of Orthodontics and Dentofacial Orthopedics* 114, pp. 418–426.

- Ghafari, J., 1997. Emerging paradigms in orthodontics—an essay. *American Journal of Orthodontics and Dentofacial Orthopedics* 111, 573–580.
- Ghafari, J., 1998. Timing the early treatment of Class II, Division 1 malocclusion: clinical and research considerations. *Clinical Orthodontics and Research* 1, 118–129.
- Ghafari, J., 1999. The role of developmental and occlusal conditions in timing orthodontic treatment. *Alpha Omegan* 92, pp. 28–35.
- Ghafari, J., 2004. Therapeutic and developmental maxillary orthopedics: evaluation of effects and limitations. In: Davidovitch, Z. & Mah, J., eds. *Biological mechanisms of tooth eruption, resorption, and replacement by implants*. Concord, MA: The Harvard Society for the Advancement of Orthodontics, pp. 167–181.
- Ghafari, J.G., 2006. The Moorrees mesh diagram: proportionate analysis of the human face. In: Jacobson A. & Jacobson R.L., eds. *Radiographic cephalometry—from basics to 3-D imaging*. 2nd ed., Chicago: Quintessence Publishing Co., pp. 161–184.
- Ghafari, J.G., 2007. Early treatment in orthodontics. *Progress in Orthodontics* 8, pp. 174–190.
- Ghafari, J., Baumrind, S. & Efstratiadis, S.S., 1998c. Misinterpreting growth and treatment outcome from serial cephalographs. *Clinical Orthodontics and Research* 1, 102–106.
- Ghafari, J. & Haddad, R.V., 2005. Relation between anterior crossbite and craniofacial anatomy in Class III malocclusion. *Journal of Dental Research* 84, p. 257 (abstract).
- Ghafari, J.G., Haddad, R.V., Saadeh, M.E., et al., 2007a. Individual appraisal of facial soft and hard tissues with the mesh diagram. *Journal of the Lebanese Dental Association* 44, pp. 15–22.
- Ghafari, J., Saadeh, M., Souccar, N. et al., 2007b. Application of systematic review in orthodontic practice. *Journal of Dental Research* 86, p. 773 (abstract).
- Ghafari, J., Shofer, F., Jacobsson-Hunt, U. et al., 1998a. Headgear versus function regulator in the early treatment of Class II, Division 1 malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics* 113, pp. 51–61.
- Ghafari, J., Shofer, F., Laster, L.L., et al., 1995. Monitoring growth during orthodontic treatment. *Seminars in Orthodontics* 1, pp. 165–175.
- Ghafari, J.G., Souccar, N. & Saadeh, M., 2008. Evidence-based dentistry: reality and dilemmas. *Journal of the Lebanese Dental Association* 45, pp. 15–22.
- Gianelly, A., 2006. Evidence-based therapy: an orthodontic dilemma. *American Journal of Orthodontics and Dentofacial Orthopedics* 129, 596–598.
- Greenhalgh, T., 1997. *How to read a paper: The basis for evidence-based medicine*. London: British Medical Group Publishing.
- Harrison, J.E., Shaw, B.C., Worthington, H.V. et al., 2002. Orthodontic treatment for prominent lower front teeth in children. *Cochrane Database of Systematic Reviews*, 1, DOI 10.1002/14651858.CD003451.
- Huang, G., 2004. Making the case for evidence-based orthodontics. *American Journal of Orthodontics and Dentofacial Orthopedics* 125, pp. 105–106.
- Huang, G., 2007. Things that make me nervous. *American Journal of Orthodontics and Dentofacial Orthopedics* 131, pp. 579–580.
- Ioannidis, J.P.A., 2005. Contradicted and initially stronger effects in highly cited clinical research. *Journal of the American Medical Association* 294, pp. 218–228.
- Kapust, A.J., Sinclair, P.M. & Turley, P.K., 1998. Cephalometric effects of face mask/expansion therapy in Class III children: a comparison of three age groups. *American Journal of Orthodontics and Dentofacial Orthopedics* 113, pp. 204–212.
- Keles, A., Cetinkaya, T., Erverdi, N. et al., 2002. Effect of varying the force direction on maxillary orthopedic protraction. *The Angle Orthodontist* 72, pp. 387–396.
- Kelly, J.E., Sanchex, M. & Van Kirk, L.E., 1973. *An assessment of the occlusion of the teeth of children 6–11 years*. Washington, DC: National Center for Health Statistics, Public Health Service, USDHEW publication no. (HRA) 74-1612 (Vital and Health Statistics; series 11, no. 130).

- Kim, J.H., Viana, M.A., Graber, T.M. et al., 1999. The effectiveness of protraction face mask therapy: a meta-analysis. *American Journal of Orthodontics and Dentofacial Orthopedics* 115, pp. 675–685.
- King, L., Harris, E.F. & Tolley, E.A., 1993. Heritability of cephalometric and occlusal variables as assessed by siblings with overt malocclusions. *American Journal of Orthodontics and Dentofacial Orthopedics* 104, pp. 121–131.
- Kircelli, B.H. & Pektas, Z.O., 2008. Midfacial protraction with skeletally anchored face mask therapy: a novel approach and preliminary results. *American Journal of Orthodontics and Dentofacial Orthopedics* 133, pp. 440–449.
- Klontz, H.A., 2006. The vertical dimension: the high-angle problem. *World Journal of Orthodontics* 7, pp. 336–344.
- Kokich, V.G., Shapiro, P.A., Oswald, R. et al., 1985. Ankylosed teeth as abutments for maxillary protraction: a case report. *American Journal of Orthodontics*. 88, 303–307.
- Macari, A.T., 2008. *Relationship between severity of malocclusion and timing of adenoidectomy and tonsillectomy*. Thesis, American University of Beirut.
- Macari, A.T. & Ghafari, J.G., 2006. Effect of compromised nasal breathing on craniofacial development. *Journal of the Lebanese Dental Association* 43, pp. 29–36.
- Merwin, D., Ngan, P., Hagg, U. et al., 1997. Timing for effective application of anteriorly directed orthopedic force to the maxilla. *American Journal of Orthodontics and Dentofacial Orthopedics* 112, pp. 292–299.
- Moyers, R.E., 1988. *Handbook of orthodontics*, 4th ed., Chicago: Year Book, pp. 410–415.
- Ngan, P., 2006. Early treatment of Class III malocclusion: is it worth the burden? *American Journal of Orthodontics and Dentofacial Orthopedics* 129, pp. S82–S85.
- Omnell, M.L. & Sheller, B., 1994. Maxillary protraction to intentionally ankylosed deciduous canines in a patient with cleft palate. *American Journal of Orthodontics and Dentofacial Orthopedics* 106, pp. 201–205.
- Oxman, A.D., Sackett, D.L. & Guyatt, G.H., 1993. Users' guide to medical literature. I. How to get started. *Journal of the American Medical Association* 270, pp. 2093–2095.
- Pangrazio-Kulbersh, V., Berger, J.L., Janisse, F.N. et al., 2007. Long-term stability of Class III treatment: rapid palatal expansion and protraction facemask vs LeFort I maxillary advancement osteotomy. *American Journal of Orthodontics and Dentofacial Orthopedics* 131, pp. 7.e9–19.
- Pelo, S., Boniello, R., Gasparini, G. et al., 2007. Maxillary corticotomy and extraoral orthopedic traction in mature teenage patients: a case report. *Journal of Contemporary Dental Practice* 8, pp. 76–84.
- Petrovic, A.G., Stutzmann, J.J. & Oudet, C.L., 1975. Control processes in the postnatal growth of the condylar cartilage of the mandible. In: McNamara, J.A., Jr., ed. *Determinants of mandibular form and growth*. Ann Arbor: Center for Human Growth and Development, University of Michigan, pp. 101–154.
- Proffit, W.R., 2000. Treatment of skeletal problems in preadolescent children. In: Proffit, W.R., ed. *Contemporary orthodontics*. 3r. ed., St. Louis: The CV Mosby Co, pp. 9–13.
- Proffit, W.R., 2007. The etiology of orthodontic problems—respiratory pattern. In: Proffit, W.R. & Fields H.W., Jr., eds. *Contemporary orthodontics*. 4th ed., St. Louis: The CV Mosby Co, pp. 130–161.
- Proffit, W.R., Fields, H.W., Jr. & Moray, L.J., 1998. Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey. *International Journal of Adult Orthodontics and Orthognathic Surgery* 13, pp. 97–106.
- Proffit, W.R., Turvey, T.A. & Phillips, C., 1996. Orthognathic surgery: a hierarchy of stability. *International Journal of Adult Orthodontics and Orthognathic Surgery* 11, pp. 191–204.
- Rabie, A.B. & Gu, Y., 2000. Diagnostic criteria for pseudo-Class III malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics* 117, pp. 1–9.

- Saadia, M. & Torres, E., 2000. Sagittal changes after maxillary protraction with expansion in class III patients in the primary, mixed, and late mixed dentitions: a longitudinal retrospective study. *American Journal of Orthodontics and Dentofacial Orthopedics* 117, pp. 669–680.
- Sackett, D., Rosenberg, W., Gray, J. et al., 1996. Evidence-based medicine: what it is and what it isn't. *British Medical Journal* 312, pp. 71–72.
- Sackett, D.L., Haynes, R.B., Guyatt, G.H. et al., 1991. *Clinical epidemiology: a basic science for clinical medicine*. 2nd ed., Boston: Little, Brown.
- Shapiro, S., 1994. Meta-analysis/shmeta-analysis. *American Journal of Epidemiology* 140, pp. 771–778.
- Stellzig-Eisenhauer, A., Lux, C.J. & Schuster, G., 2002. Treatment decision in adult patients with Class III malocclusion: orthodontic therapy or orthognathic surgery. *American Journal of Orthodontics and Dentofacial Orthopedics* 122, pp. 27–38.
- Stockli, P.W. & Teuscher, U.M., 1985. Combined activator headgear orthopedics. In: Graber, T.M. & Swain, B.F., eds. *Orthodontics: current principles and techniques*. St. Louis: The CV Mosby Co, pp. 405–484.
- Suda, N., Ishii-Suzuki, M., Hirose, K. et al., 2000. Effective treatment plan for maxillary protraction: is the bone age useful to determine the treatment plan? *American Journal of Orthodontics* 118, pp. 56–62.
- Sugawara, J. & Mitani, H., 1993. Facial growth of skeletal Class III malocclusion and the effects, limitations, and long-term dentofacial adaptations to chin-cap therapy. *Seminars in Orthodontics* 3, pp. 244–254.
- Sung, S.J. & Baik, H.S., 1998. Assessment of skeletal and dental changes by maxillary protraction. *American Journal of Orthodontics and Dentofacial Orthopedics* 114, pp. 492–502.
- Toros, A., Keles, A. & Erverdi, N., 2000. The effects of a modified protraction headgear on maxilla. *American Journal of Orthodontics and Dentofacial Orthopedics* 117, pp. 27–38.
- Tortop, T., Keykubat, A. & Yuksel, S., 2007. Facemask therapy with and without expansion. *American Journal of Orthodontics and Dentofacial Orthopedics* 132, pp. 467–474.
- Troy, B.A., Shanker, S., Fields, H.W. et al., 2009. Comparison of incisor inclination in patients with Class III malocclusion treated with orthognathic surgery or orthodontic camouflage. *American Journal of Orthodontics and Dentofacial Orthopedics* 135, pp. 146.e1–9; discussion 146–147.
- Tung, A. & Kiyak, A., 1998. Psychological influences on the timing of orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* 113, pp. 29–39.
- Turley, P.K., 2002. Managing the developing Class III malocclusion with palatal expansion and facemask therapy. *American Journal of Orthodontics and Dentofacial Orthopedics* 122, pp. 349–352.
- Vardimon, A.D., Graber, T.M., Stutzmann, J. et al., 1994. Reaction of the pterygomaxillary fissure and the condylar cartilage to intermaxillary Class III magnetic mechanics. *American Journal of Orthodontics and Dentofacial Orthopedics* 105, pp. 401–413.
- Vaughn, G.A., Mason, B., Moon, H.B. et al., 2005. The effects of maxillary protraction therapy with or without rapid palatal expansion: a prospective, randomized clinical trial. *American Journal of Orthodontics and Dentofacial Orthopedics* 128, pp. 299–309.
- Westwood, P.V., McNamara, J.A., Jr., Baccetti, T. et al., 2003. Long-term effects of Class III treatment with rapid maxillary expansion and facemask therapy followed by fixed appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* 123, pp. 306–320.
- Wolff, S.H., Battista, R.N., Anderson, G.M. et al., 1990. Assessing the clinical effectiveness of preventive maneuvers: analytic principles and systematic methods in reviewing evidence and developing clinical practice recommendations. A report by the Canadian Task Force on the Periodic Health Examination. *Journal of Clinical Epidemiology* 43, pp. 891–905.
- Yuksel, S., Ucem, T.T. & Keykubat, A., 2001. Early and late facemask therapy. *European Journal of Orthodontics* 21, pp. 559–568.

Part 3

Evidence-Based Orthodontics in Perspective

Evidence-Based Care in Context

**William Shaw, BDS, MScD, PhD, FDSRCS, DOrth RCS,
DDOrth RSCP**

University Dental Hospital of Manchester, Manchester, UK

As in other aspects of health care, the achievement of optimal outcomes requires a practitioner who excels in three domains: aspiration, clinical skill, and treatment choice. High aspiration stems from a number of personal values, education, and working environment, including the financial and organizational context. Clinical skills, including the ability to motivate and support patients, may also reflect innate personal qualities and talent, together with the extent and quality of training and experience. But making the right choice in treatment depends mostly on the practitioner's access to a sound store of evidence on the probability that particular lines of treatment, technologies, or materials are better than others. Typically in orthodontics, therapeutic choices will be deemed successful if they are reliable and robust (they usually work), economical (low chair-side time and delivery cost), user friendly (comfortable and undemanding), and safe.

Unlike aspiration and skill, maintenance of a sound evidence base requires a collective professional effort, as no single individual would be able to conduct the research necessary to resolve the huge level of uncertainty that prevails today. Furthermore, the standing of a health profession is largely a reflection of the collective effort that has been made to establish the evidence base underpinning its activity.

As described elsewhere in this book, well-conducted randomized control trials of competing treatments and technologies incorporating patient-centered outcomes are less likely than other forms of comparison to incorporate bias, and systematic reviews of well-conducted trials will provide the surest means of resolving uncertainty.

This chapter provides an overview of the trials reported in the orthodontic literature, their source and the quality of reporting, and how the profession, journals, and agencies such as The Cochrane Collaboration might work together to improve the orthodontic profession's evidence base.

Trials in the Orthodontic Literature

As Table 17.1 shows, randomized control trials (RCTs) constitute a lower proportion of the clinical reports in orthodontics' largest journal than in other speciality journals in dentistry.

This is perhaps surprising given the predominately “hands-on” clinical nature of orthodontics and the constant stream of clinical innovations from practice and of new technologies from the orthodontic materials and devices industry. True, the actual numbers of RCTs and CCTs (controlled clinical trials) reported have been increasing since the 1980s, but not more than in the general area of oral health (Figures 17.1 and 17.2).

Figure 17.3 summarizes the countries in which reported trials were carried out.

The number of trials appears to bear little relationship to the size of the country (for example, the rank order of the eight most prolific have populations of 62, 309, 72, 193, 82, 60, 22, and 127 million, respectively).

Table 17.2 provides an overview of the topics investigated in 191 clinical trials reported during the period 2000–2009, and all appear to address questions of relevance to the everyday practice of orthodontics. Indeed an orthodontist who knew how best to negotiate

Table 17.1 Percentage of clinical reports that are RCTs in different journals.

	%
<i>Journal of Clinical Periodontology</i>	26.7
<i>Caries Research</i>	25.0
<i>Journal of Periodontology</i>	13.3
<i>Oral Surgery, Oral Medicine, and Oral Pathology</i>	7.4
<i>American Journal of Orthodontics and Dentofacial Orthopedics</i>	4.1

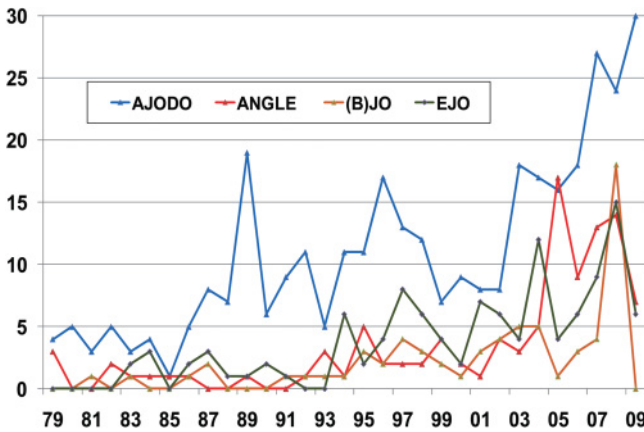


Figure 17.1 The number of RCTs and CCTs published annually in the major orthodontic journals. AJODO, American Journal of Orthodontics and Dentofacial Orthopedics; (B)JO, British Journal of Orthodontics; EJO, European Journal of Orthodontics.

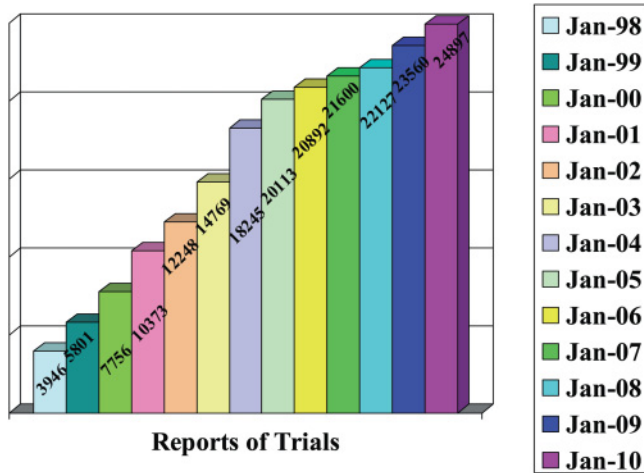


Figure 17.2 The number of RCTs and CCTs published annually on oral health topics.

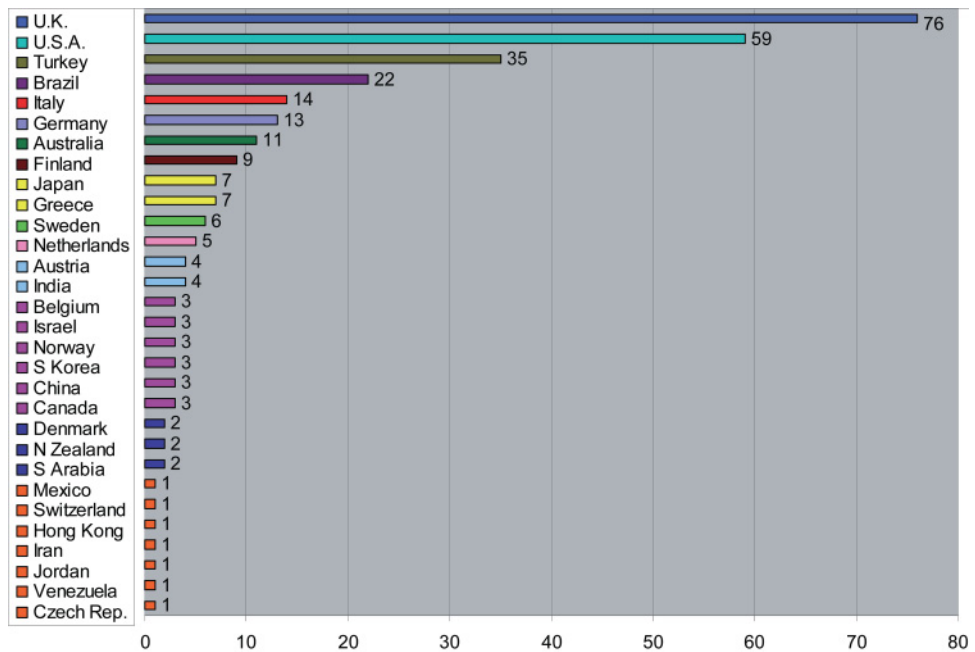


Figure 17.3 Number of reports of orthodontic trials published from 2000 to 2009 according to country in which they were performed.

the uncertainties in these areas would have a very much enhanced probability of delivering optimal care.

Sadly, however, even a cursory review of these reports reveals that many trials are inconclusive because of small sample size, less than rigorous trial management, and poor reporting, especially concerning the method of allocation concealment. Harrison (2003)

Table 17.2 Trial topics 2000–2009.

Various treatments	70	Oral hygiene	23
Bonding/banding	64	Sleep apnea	8
Class II/functionals	46	Compliance/communication	6
Caries prevention	23	Education	4
Resorption/tissue reactions	23	Tooth movement	2
Pain/trauma	20	Retention	5
Arch expansion	14	Bacteraemia	1
Alignment/retraction	15		=325

found that only 2.6% of 155 orthodontic trials published between 1989 and 1998 adequately reported their method of allocation concealment. The CONSORT statement (consolidated standard of reporting trials) was published in 1996, and subsequently revised in 2001, in an attempt to improve the quality of reporting of RCTs (Moher et al. 2001). In a further survey of orthodontic trials, Harrison found that the standard of reporting trials improved somewhat in journals that required authors to complete the CONSORT checklist, but not by a significant amount as journals appeared not to ensure compliance (Flint and Harrison 2010).

The Cochrane Oral Health Group

The Cochrane Collaboration started in 1993 with the following aim: “Improving healthcare decision-making globally, through systematic reviews of the effects of healthcare interventions, published in The Cochrane Library.” It is an “international not-for-profit and independent organization, dedicated to making up-to-date, accurate information about the effects of healthcare readily available worldwide.” Its primary function is the production and dissemination of high-quality systematic reviews of health-care interventions. The rationale for systematic reviews has been well documented over the years (Mulrow 1994; Chalmers & Altman 1995). Simply, they aim to reduce the ever-increasing volume of both published and unpublished research literature on a specific topic into manageable, unbiased, quality-assessed portions.

The Cochrane Collaboration is made up of over 50 review groups, of which the Cochrane Oral Health Group (COHG) is one. Originally established in 1994 in the United States by Alexia Antczak Bouckoms, the editorial base for the COHG transferred to the School of Dentistry, University of Manchester, UK, in 1996 with Professors Bill Shaw and Helen Worthington as coordinating editors. Funding for core staff at the editorial base is provided by the UK’s Department of Health; the collaboration as a whole relies entirely on grants and donations and does not accept conflicted funding.

Over the last 15 years, the COHG has developed as an extremely productive, international network of health-care practitioners, decision makers, researchers, and consumers. The aim of the group is primarily to produce systematic reviews of randomized controlled trials focusing on the prevention, treatment, and rehabilitation of oral, dental, and cranio-facial diseases and disorders. Many of these reviews are undertaken by highly motivated volunteers, keen to find “the answer” to a question that is of clinical relevance to them.

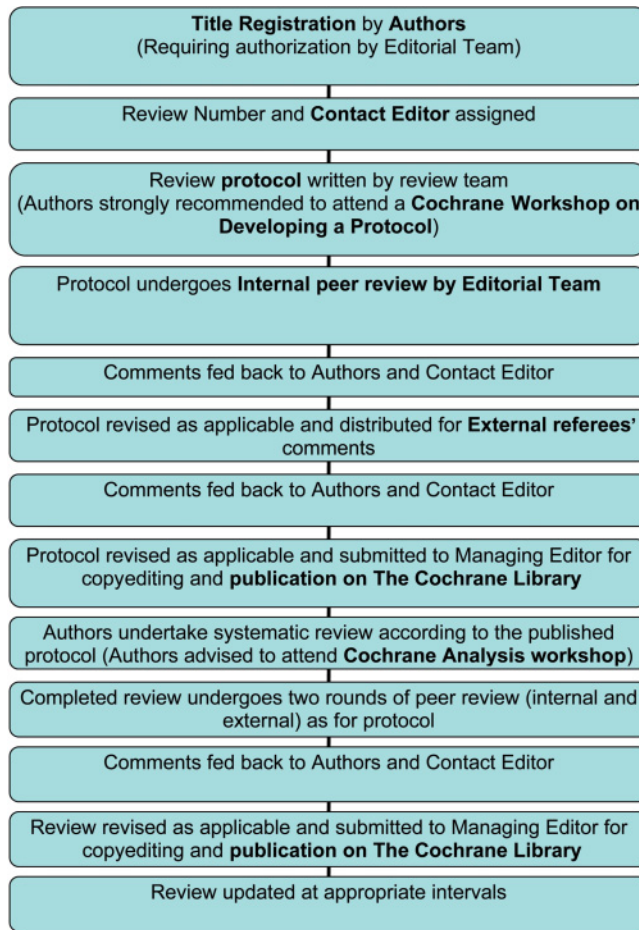


Figure 17.4 Cochrane Oral Health Group editorial process.

Reviewers are supported throughout the process by the editorial team, who is able to provide clinical, statistical, methodological, and technical advice as required.

The COHG aims to have a transparent, rigorous editorial process (see Figure 17.4) that ensures all registered review titles, protocols, and completed reviews go through extensive peer review.

The managing editor for the COHG is responsible for coordinating the whole process, the key elements of which involve title registration, requiring potential authors to provide justification for the chosen topic, details of the proposed review team including their experience of systematic review methodology, and an indication of training needs. Once a title has been approved, the review team is required to develop a detailed protocol (with training available in the form of the Cochrane workshop on developing a protocol). The protocol undergoes peer review by the editorial team and selected external referees prior to publication on the Cochrane Database of Systematic Reviews (CDSR), one of several databases on The Cochrane Library. The assigned contact editor for the review serves as liaison for the authors to ensure all relevant comments are addressed and also that there

is no duplication of effort due to having two systematic reviews addressing the same question. By publishing the protocol, the collaboration aims to reduce bias in the review process by allowing readers across the world to comment on the methods to be used. Once a protocol has been accepted for publication, authors undertake the systematic review according to the methods described. The editorial team is available to provide advice and support throughout the review process, and authors are encouraged to attend the Cochrane Analysis workshop. The completed review will, again, undergo further scrutiny, thorough rounds of both internal and external peer review, providing comments that can be discussed with the contact editor. The process does not end with the completion of the full systematic review; Cochrane Reviews are “living” documents that are updated at regular intervals. Typically, this could be every 2 years but may depend upon the volume and clinical relevance of the emerging research.

In addition to the production of systematic reviews for the CDSR, the COHG is responsible for maintaining a trials register of reports of controlled clinical trials (CCTs) and randomized controlled trials (RCTs) relating to oral health. The content of the register is the product of comprehensive electronic searching and hand searching, identifying both published and unpublished reports of trials. The number of reports currently listed in the register is approaching 25,000, making the register a highly valuable resource for all those wishing to identify RCTs/CCTs of oral health. New records added to the trials register are updated quarterly to CENTRAL, a database of clinical trials also published on The Cochrane Library. In addition to CDSR and CENTRAL, The Cochrane Library publishes five further databases (listed in Table 17.3). The Cochrane Library is published quarterly by Wiley InterScience. It is available on a subscription basis online or on DVD-ROM. Individual reviews are also available on a pay-per-view basis. Residents in a number of countries or regions can access The Cochrane Library online for free through a “provision” or a special scheme, including Australia, parts of Canada and the United States, Denmark, Finland, India, Ireland, Latin America and the Caribbean, Norway, Spain, Sweden, New Zealand, and the United Kingdom. The Cochrane Library is also available free of charge to all residents of countries in the World Bank’s list of low-income economies. Recent developments have included the production of audio summaries or podcasts of selected reviews from The Cochrane Library and the initiation of the Cochrane Journal Club (www.cochranejournalclub.com).

The Oral Health Group currently has 96 reviews and 77 protocols published on the Cochrane Library (www.ohg.cochrane.org/).

Table 17.3 Databases included in The Cochrane Library.

Cochrane Database of Systematic Reviews (CDSR; Cochrane reviews)
Database of Abstracts of Reviews of Effects (DARE; Other systematic reviews)
Cochrane Central Register of Controlled Trials (CENTRAL; clinical trials)
Cochrane Methodology Register (CMR; methods studies)
Health Technology Assessment Database (HTA; technology assessments)
NHS Economic Evaluation Database (NHSEED; economic evaluations)
About The Cochrane Collaboration (about; Cochrane groups)

Cochrane Reviews Relevant to Orthodontics

Table 17.4 lists reviews completed or in process that have relevance to orthodontic practice, but with the possible exception of the review of early Class II treatment, the paucity of good orthodontic clinical trials will continue to limit the recommendations for practice that may be made. Nonetheless, systematic reviews that essentially report the lack of evidence may still benefit the development of the evidence base in two ways: by influencing the choice of topics that research funding agencies are willing to invest in and by

Table 17.4 Summary of Cochrane reviews related to orthodontics, completed or in progress.

Published Reviews

Adhesives for fixed orthodontic bands (updated issue 2, 2007)
 Adhesives for fixed orthodontic brackets
 Arthrocentesis and lavage for treating temporomandibular joint disorders
 Extraction of primary (baby) teeth for unerupted palatally displaced permanent canine teeth in children
 Feeding interventions for growth and development in infants with cleft lip, cleft palate or cleft lip and palate
 Fluorides for the prevention of white spots on teeth during fixed brace treatment
 Interspace/interdental brushes for oral hygiene in orthodontic patients with fixed appliances
 Interventions for the management of submucous cleft palate
 Occlusal adjustment for treating and preventing temporomandibular joint disorders
 Occlusal splints for treating sleep bruxism (tooth grinding)
 Open versus closed surgical exposure of canine teeth that are displaced in the roof of the mouth
 Oral appliances and functional orthopedic appliances for obstructive sleep apnea in children
 Orthodontic and orthopedic treatment for anterior open bite in children
 Orthodontic treatment for deep bite and retroclined upper front teeth in children (updated issue 1, 2009)
 Orthodontic treatment for posterior crossbites (updated issue 1, 2001)
 Orthodontic treatment for prominent upper front teeth in children
 Reinforcement of anchorage during orthodontic brace treatment with implants or other surgical methods
 Retention procedures for stabilizing tooth position after treatment with orthodontic braces
 Stabilization splint therapy for temporomandibular pain dysfunction syndrome

Reviews in the Refereeing Process

Initial arch wires for alignment of crooked teeth with fixed orthodontic braces (to be published issue 4, 2010)
 Orthodontics for treating temporomandibular joint (TMJ) disorders

(Continued)

Table 17.4 Summary of Cochrane reviews related to orthodontics, completed or in progress. (*Continued*)

Published Protocols

Adhesives for bonded molar tubes during fixed brace treatment
 Anterior repositioning splint for temporomandibular joint disc displacement (figures)
 Interventions for space closure in orthodontic treatment
 Optimum force for tooth movement in orthodontic treatment
 Orthodontic treatment for crowded teeth in children
 Orthodontic treatment for distalizing upper front molars
 Orthodontic treatment for prominent lower front teeth in children
 Secondary bone grafting for alveolar cleft in children with cleft lip or cleft lip and palate
 Self-ligating orthodontic braces for straightening teeth

Protocols in the Refereeing Process

Interventions for correcting relapse of the lower front teeth after orthodontic treatment
 Presurgical orthopedics for infants with complete cleft lip and palate
 Timing of hard palate repair for cleft lip and palate

Registered Titles

Direct versus indirect bonding for fixed orthodontic brackets
 Laceback ligatures for controlling anchorage in patients undergoing fixed orthodontic treatment
 Orthodontic treatment for bimaxillary proclination

providing a firm basis for planning definitive trials. In the United Kingdom, the National Institute for Health Research uses reviews pointing to clinical uncertainty to determine policy on calls for research applications. For example, the Cochrane Oral Health Group review on Bell's palsy led to investment in a trial that established optimal treatment, and the group's review on recall intervals led to investment in a trial of risk-based intervals. More recently, a systematic review highlighting the lack of evidence on strategies for managing otitis media with effusion in children with cleft palate led to a call for applications to carry out a feasibility study for a major trial. Uncertainty in the treatment of head and neck cancer also prompted the National Institutes of Health in the United States to commission the Cochrane Oral Health Group to undertake a series of systematic reviews.

Collective Action to Improve the Evidence Base for Orthodontics

There is no doubt that The Cochrane Collaboration and its protocols for synthesizing and disseminating quality-controlled summaries of best evidence can play a significant role in promoting evidence-based orthodontic care. Orthodontists are well represented in the Cochrane Oral Health Group, and there is already a cadre of experienced orthodontic reviewers. The challenge for orthodontics is that a major step change is required to increase

the scale and quality of clinical trials and to increase the profession's collective will to become truly evidence based. There are many ways to straighten teeth, and choosing between bracket/adhesive combinations and extraction patterns may often come down to individual practitioner preference. On the other hand, some treatments may have advantages that would simplify, hasten, or ease courses of treatment. At the present time, we mostly don't know. But we do have some remarkably wide differences in the way that care is provided across the profession.

University departments clearly have a significant role in educating today's students to become the critical, selective practitioners of tomorrow. Likewise, universities will have an ongoing role in developing and coordinating research. However, the landscape for clinical research has changed substantially in the last decade. Far more demanding research governance is required to ensure ethical and confidentiality compliance, and a far higher level of sophistication and multidisciplinary in trial design and management is now expected by funding agencies. Lasting partnerships between academic researchers and networks of practitioners in the "real world" are now essential to achieve appropriately powered studies that will yield conclusions that can be generalized to everyday circumstances. Journals can raise the quality and reporting of trials by insisting on adherence to CONSORT checklists. But the real responsibility for promoting and fostering research should fall on the profession as a whole, led by its national and international representative bodies. These will need to become engaged in promoting research-based practices, providing pump-priming research grants, and canvassing major funding agencies to invest in orthodontic research. It can't be done on the cheap.

If we are left behind, our standing as a professional group will fall, and we will be open to the kind of observation that David Sackett, a pioneer of evidence-based medicine, made in 1985: "Orthodontics is behind such treatment modalities as acupuncture, hypnosis, homeopathy, and orthomolecular therapy, and on a par with scientology, dianetics and podiatry".

References

- Chalmers, I. & Altman, D., 1995. *Systematic reviews*. London: BMJ Publishing Group.
- The Cochrane Collaboration. The reliable source of evidence in health care. Available from: <http://www.cochrane.org/> [Accessed October 28, 2009].
- Flint, H.E. & Harrison, J.E., 2010. How well do reports of randomised controlled trials, reported in the orthodontic literature, comply with the CONSORT statement? *Journal of Orthodontics* 37, pp. 250–261.
- Harrison, J.E., 2003. Clinical trials in orthodontics II: assessment of the quality of reporting of clinical trials published in three orthodontic journals between 1989 and 1998. *Journal of Orthodontics* 4, pp. 309–315.
- Moher, D., Schulz, K.F. & Altman, D.G., 2001. The CONSORT statement: revised recommendations for improving the quality of reports of parallel-group randomized trials. *Ann Intern Med* 13, pp. 657–662.
- Mulrow, C., 1994. Rationale for systematic reviews. *British Medical Journal* 309, pp. 597–599.
- Sackett, D.L. 1986. The science of the art of clinical management. In: P.S. Vig & K.A. Ribbens, eds. *Science and clinical judgement in orthodontics*. Vol. 19, Craniofacial Growth Series. Ann Arbor, MI: University of Michigan, Center for Human Growth and Development.

Playing Doctor: Evidence-Based Orthodontics

Lysle E. Johnston, Jr., DDS, MS, PhD, FDSRCS

Professor Emeritus of Dentistry, Department of Orthodontics and Pediatric Dentistry, The University of Michigan, Ann Arbor, MI; Professor Emeritus of Orthodontics, Department of Orthodontics, Center for Advanced Dental Education, Saint Louis University, St. Louis, MO

I was asked by the editors to address the limitations of evidence-based orthodontics (EBO). To me, the EBO movement is merely a sensible exhortation to use the best available data in the treatment of individual patients. Its ultimate limitation, therefore, is the soundness of the best available information. Beyond that, the trick is to figure out what that best treatment is. In my naïveté, I am surprised that this reasonable step is so controversial. Market pressures aside, I can see only two potential limitations to the EBO decision process: the specialty's attitude toward evidence and the quality of the evidence itself. Unfortunately, the former tends to trump the latter.

Contemporary orthodontics is dominated by desultory conflict. Extraction versus expansion (with the correct bracket and archwire, of course) and one stage versus two are obvious examples. In a perfect world, one might expect the specialty to look to its researchers in both "town and gown" to generate evidence upon which decisions can be based. To a first approximation, our controversies, although clinically important, are relatively simple, and the questions they generate are obvious. Can expansion be an effective substitute for extraction? Is it stable? Does a first stage add value to a treatment? If it does, what is the value and under what circumstances does it accrue? In orthodontics, however, those who attempt to answer these questions and the methods they use often are seen as the problem rather than the solution. I will argue that this attitude of studied contempt and inattention is perhaps the real limitation. How can it have come to this?

Malocclusion isn't a disease; treatment success and failure are ill-defined. Indeed, experience teaches that everything works well enough to support a practice. You use your methods, I'll use mine. Because history reveals its alternatives neither to the individual patient nor to the clinician, the differences among treatments, no matter how great, are of little practical significance to the orderly flow of commerce. When everything works, science can be an unwelcome intrusion. Controversy is license. Good news for the orthodontist; bad news for the specialty.

Imagine, if you will, that a NASA tracking station has received a message from an infinitely advanced civilization saying that a robot is about to land at home base in Yankee Stadium (I have in mind something like Gort from *The Day the Earth Stood Still*). The purpose of this interstellar mission is to end sectarian violence and mistrust by telling us whether God exists, and, if so, which of our religions is the True Faith. Do you think the religious leaders of the World would rush to New York, beatific smiles on their faces, eager to join hands and learn the truth? Somehow I doubt it. I suspect that only a scattering of atheists and agnostics would welcome such an amazing revelation. For the rest, it would be a potentially catastrophic, soul-shattering event: at best, $N - 1$ religions would turn out to be "wrong" and thus in need of replacement by a foreign, perhaps even alien, belief system. Given that religions tend to feature ethical guidelines and precepts that support a "successful" life (however you may wish to define success), the impact of such a truth on our day-to-day lives would be beyond comprehension. In orthodontics, evidence is the intrusion that threatens the "philosophical" foundation of thousands of "successful" practices. Who or what is to blame? The schools, their researchers, and this "evidence-based treatment" nonsense!

Generating evidence in its various forms is a major part of a university's mission. Nearly a century ago, when proprietary institutions fell into disrepute, orthodontics needed a respectable home. The universities seemed a perfect choice. Indeed, our founding fathers—folks like Kingsley, Angle, Farrar, Hellman, and Case—as well as the leaders who followed, took as an article of faith the proposition that orthodontics is a science. We belonged in academia. Unfortunately, our leaders occasionally championed, in the name of science, fanciful, idiosyncratic, largely unproved treatment "philosophies," some aspects of which were so recondite that they could only be quoted verbatim. Angle's definition of the "line of occlusion" (1907) is a telling example: "... The line with which in form and position according to type the teeth must be in harmony if in normal occlusion." Unfortunately, many of these guiding principles were unrecognizable as science by the academic establishments in which we had sought refuge: facial growth is controlled by trophic substances oozing out of *foramen rotundum*; the upper molars cannot be moved distally; given the right force, tooth movement can grow bone; there exist reciprocal forces that will move canines but not molars; there exist reciprocal forces that will move molars but not canines; facial proportions do not change over time; if done properly, expansion is an effective substitute for extraction; airway expansion is the key to facial growth (rather than vice versa); proper facial development requires 32 teeth; in time, "growth" will ameliorate lower incisor crowding; malocclusion causes temporomandibular discrepancies (TMD); orthodontics can cure TMD, etc. Despite what "pointy-headed academics" might say, the various schools of thought feature—and always have featured—ideas and methods that can in fact support a successful practice. Isn't this very success proof that contemporary practice is "evidence-based"? It is if survival is the only criterion. After all, history teaches that in orthodontics everything works well enough to pay the bills.

Clearly, there is a major philosophical problem with a nihilistic approach to treatment: if we were to clone a patient and have 100 orthodontists render treatment, there would be 100 treatment plans and 100 outcomes; however, only one would be best. Wouldn't members of a learned specialty with medical/scientific aspirations want to know which of these treatments works best for a given patient? Apparently not, especially at a time when we can't even agree on a definition of success beyond parallel roots and even marginal ridges. Given that nobody dies from anchorage loss, evidence is, for many, an unnecessary elaboration that serves only to impede the orderly flow of commerce. Expansion? Who knows? Perhaps it will work. After all, referring dentists don't like extraction, and space closure is hard work. Perhaps a year of "functional" therapy will help. After all, what harm can it do? Besides, we can always pretend that second-phase brackets can grow bone and employ permanent retention until the patient moves or we retire. Aesthetics? People like "full" profiles; the teeth smooth out the wrinkles. The discussion usually ends with the calming folk wisdom that "there are many ways to skin a cat." True; however, only one way is best. EBO is under attack because it threatens to reveal this best way and in so doing discredit many of the treatments that are the bedrock of contemporary clinical practice. To those who champion a *laissez faire*, live-and-let-live approach to practice, the *bête noir* is the randomized clinical trial.

All clinical data are not created equal; there is a generally accepted hierarchy headed by the structured review of prospective randomized clinical trials (RCTs). The purpose of the RCT is to characterize the effect of a given treatment. Randomization is the key: it protects against biases, both known and unknown. In medicine, the RCT is the gold standard; in orthodontics, it is anathema. Why? Simply because randomized clinical trials often come up with unpopular results. In orthodontics, the most despised of RCTs are those designed to characterize the impact of "early treatment." As summarized in a Cochrane review of eight RCTs (592 subjects), Harrison, O'Brien & Worthington (2007) concluded that "Early orthodontic treatment (Phase I), followed by a later phase of treatment (Phase II) when the child is in early adolescence, does not appear to have any advantages over treatment that is provided in one phase when the child is in early adolescence." Our response to these RCTs? The editor of the *Great Lakes Association of Orthodontists Newsletter* (Monticello 2004) weighed in for organized orthodontics:

... I am truly disappointed that the editorial staff at the ADA would accept such material as their feature cover story with such far reaching conclusions stated and endorsed as evidence based FACT and as closing the case on Two-Phase therapy. What a travesty.

To discredit such "inconvenient truths," many critics have advanced a truly amazing/embarrassing misinterpretation of the nature of an RCT. Apparently not having heard of "equipose" (Freedman 1987), they complain that it is unethical to assign treatments according to a coin toss. They argue that, had experienced clinicians chosen and executed the treatments based on some sort clinical intuition, it would have been possible to discover benefits that have escaped the gaze of less clinically adept academic nonbelievers. Indeed, every aspect of the RCT has been subjected to relatively trivial nit-picking. For example, if Class II is defined by ANB, it is argued that this approach can be insensitive to Angle classification. Of course, if Angle's classification were to have been used, it would be argued that the "Class II" category is insensitive to skeletal discrepancies, such as those measured by ANB. Zuccati, Clauser & Giorgetti (2009) have presented a succinct counter

to the untutored objections commonly raised in our literature. Furthermore, there are many comparative reviews and editorials that detail the strengths and weaknesses of the various designs (e.g., Benson & Hartz 2000; O'Brien 2001; Hannan 2008). Bottom line: all things being equal, bet on the RCT. Unfortunately, in the world of orthodontics, all things are not equal. I would argue that, in its orthodontic incarnation, the RCT features a number of obvious shortcomings. Though unavoidable and perhaps benign, these problems receive little, if any, comment in the literature.

And why beholdest thou the mote that is in thy brother's eye, but considerest not the beam that is in thine own eye? Matthew 7:3

Among the orthodontic *cognoscenti* who conduct prospective randomized clinical trials, there is a tendency to see the means of investigation as an end unto itself and, by extension, to discount all other sources of data. They apparently feel that the road to scientific maturity—and generous funding—lies in imitating medicine, regardless of the compromises that may be required. In the words of The Great Oz, “Pay no attention to that man behind the curtain.”

In orthodontic trials, the goodness of the outcome often seems to depend on the orthodontist's efforts and the patient's cooperation, both of which surely will be elevated to supranormal levels by dint of their known, unblinded participation in a clinical trial. Thus, I would argue that many of our RCTs overstate the effectiveness of the treatments being studied. Furthermore, orthodontic treatments take years to finish and even longer to evaluate. Thus, a nontrivial RCT might take 15–20 years, cost as much as a major medical trial, and be burdened by a staggeringly large Hawthorne effect. Given this extended time frame, such a trial also probably would outlive both its working hypothesis and its principal investigators. We need to be as selective in our choice of research methods as we are mindful of the data they generate. Clearly, the RCT is the gold standard in medicine; however, the answers it generates are not the only answers and occasionally not even the right answers. As noted by Concato, Shah & Horwitz (2000):

Contrary to prevailing beliefs, the “average results” from well-designed observational studies (with a cohort or case-control design) did not systematically overestimate the magnitude of the associations between exposure and outcome as compared with the results of randomized, controlled trials of the same topic. Rather, the summary results of randomized, controlled trials and observational studies were remarkably similar for each clinical topic we examined. Viewed individually, the observational studies had less variability in point estimates (i.e. less heterogeneity of results) than randomized, controlled trials on the same topic. In fact, only among randomized, controlled trials did some studies report results in a direction opposite that of the pooled point estimate, representing a paradoxical finding (e.g. treatment of hypertension was unexpectedly associated with higher rates of coronary heart disease in several clinical trials).

... The popular belief that only randomized, controlled trials produce trustworthy results and that all observational studies are misleading does a disservice to patient care, clinical investigation, and the education of health care professionals.

For orthodontics, an occasional incorrect answer is not the major problem. Instead, we must face the fact that, for many questions, the RCT might be incapable of generating any answer at all. We will have to look to other, less exalted sources of data.

In my Father's house are many mansions. John 14:2

The only treatments that can be assigned at random are those to which a subject is both indifferent and equally susceptible. Do you want to compare slot sizes or bracket designs? Archwire materials? Retention methods? Temporary anchorage devices? If you have the time and the money, the RCT is at the top of the pyramid of evidence; however, what about more significant questions featuring less benign options? How could surgery versus orthodontic "camouflage" be randomized to a fully informed adult? How about extraction versus expansion? Would a prospective subject really not care how the coin toss came out? Shaw (2000) is optimistic; I am not. Although Korn and Baumrind (1991) have developed a method by which it might be possible to randomize these sorts of treatments, I am not convinced that it would pass muster, either with an institutional review board or a fully informed subject. If 21st century orthodontic practice is to be "evidence based," I would argue that clinicians often will have to rely on data generated by thoughtful non-randomized designs.

For example, to compare treatments to which few, if any, fully informed subject could be indifferent (say, extraction/nonextraction or orthodontics/surgery), it is possible to use Miettinen's method of "confounder summarization" (Miettinen 1976). In this approach, discriminant analysis is used to identify subjects who were similar at the outset but who subsequently were treated differently. In effect, it identifies subjects who could have been enrolled in a randomized trial. If the groups were similar at the outset, differences at recall (perhaps many years posttreatment) would estimate the effects of the treatments under investigation. It is a quick, relatively inexpensive way of minimizing susceptibility bias in a retrospective/prospective comparison of treatments that probably cannot be assigned at random (Paquette, Beattie & Johnston 1992; Cassidy et al. 1993; Beattie, Paquette & Johnston 1994; Livieratos & Johnston 1995). Neither the patients nor the providers would have known they were ever going to be part of a study; hence, there would be no concern about blinding or distortion by a Hawthorne effect. On the negative side of the ledger is the lack of randomization. Although it is difficult to see how bias could creep into this approach, one can never be 100% certain. Feinstein (1983), however, cautions such concern may be a "misconception":

... To give randomization credit for certain scientific standards and precautions for which it is really not responsible. ... The misconception just cited—which confuses the tactic of randomized assignment and the strategy of a scientific plan—is particularly important, because many of the desirable scientific features associated with randomized clinical trials ... are really attributable to advance scientific planning, not to randomization. These desirable features can therefore be obtained with suitable planning even when randomization is not used.

A cynic might infer from our literature that the real drawback of lesser designs is that one loses membership in the RCT community, with all the rights and privileges pertaining thereunto. Indeed, to maintain one's standing, it apparently is important never to acknowledge the existence of alternative methods, let alone their results. Thus, if the only way to answer a given question is by way of a method considered *déclassé*, then it should come as no surprise that the question neither gets asked nor answered. Absent data, it then can be claimed truthfully on behalf of even our most questionable treatments that they are based on "the best available evidence." Live and let live; I'm OK, you're OK.

In Boston society, it used to be said that the Lodges speak only to the Lowells, the Lowells speak only to the Cabots, and the Cabots speak only to God. As long as the RCT devotees speak only to themselves and to God about relatively trivial questions, the important and controversial issues—expansion, extraction, surgery, “bone-growing,” TMD “diagnosis,” and the like—will languish in a Limbo of our own making. There is a danger, therefore, that the real legacy of the RCT will be an arrogance that, by the law of unintended consequences, will prevent an investigation of treatments that cannot be randomized to a fully informed subject. Rather than having the effect of weeding out the ineffective, unlikely, and patently lunatic, our version of “evidence-based practice” in the end may serve only to guarantee that the jury will be out ... forever.

After 3000 words, this short polemic has wandered full circle. The limitations of EBO’s decision process are the specialty’s attitude toward evidence and the quality of the evidence, itself. We have met the enemy and he is us.

References

- Angle, E.H., 1907. Treatment of malocclusion of the teeth. *Angle’s System*. 7th ed., Philadelphia: The S.S. White Dental Manufacturing Co.
- Beattie, J.R., Paquette, D.E. & Johnston, L.E., Jr., 1994. The functional impact of extraction and nonextraction treatments: a long-term comparison in “borderline,” equally-susceptible Class II patients. *American Journal of Orthodontics and Dentofacial Orthopedics* 105, pp. 444–449.
- Benson, K. & Hartz, A.J., 2000. A comparison of observational studies and randomized, controlled trials. *New England Journal of Medicine* 342, pp. 1878–1886.
- Cassidy, D.W., Jr., Herbosa, E.G., Rotskoff, K.S. et al., 1993. A comparison of surgery and orthodontics in “borderline” Class II, Division 1 adults. *American Journal of Orthodontics and Dentofacial Orthopedics* 104, pp. 455–470.
- Concato, J., Shah, N. & Horwitz, R.I., 2000. Randomized controlled trials, observational studies, and the hierarchy of research designs. *New England Journal of Medicine* 342, pp. 1887–1892.
- Feinstein, A.R., 1983. An additional basic science for clinical medicine: III. The challenges of comparison and measurement. *Annals of Internal Medicine* 99, pp. 705–712.
- Craniofacial Growth Series*, volume 18. Ann Arbor, MI: Center for Human Growth and Development, The University of Michigan, pp. 1–14.
- Freedman, B., 1987. Equipoise and the ethics of clinical research. *New England Journal of Medicine* 31, pp. 141–145.
- Hannan, E.H., 2008. Randomized clinical trials and observational studies: guidelines for assessing respective strengths and weaknesses. *JACC: Cardiovascular Interventions* 1, pp. 211–217.
- Harrison, J.E., O’Brien, K.D. & Worthington, H.V., 2007. Orthodontic treatment for prominent upper front teeth in children. *Cochrane Database of Systematic Reviews*, 3. Art. No. CD003452, DOI 10.1002/14651858.CD003452.pub2.
- Korn, E.L. & Baumrind, S., 1991. Randomised clinical trials with clinician-preferred treatment. *Lancet* 337, pp. 149–152.
- Livieratos, F.A. & Johnston, L.E., Jr., 1995. A comparison of one- and two-stage non-extraction alternatives in matched Class II samples. *American Journal of Orthodontics and Dentofacial Orthopedics* 108, pp. 118–131.
- Miettinen, O.I., 1976. Stratification by a multivariate confounder score. *American Journal of Epidemiology* 104, pp. 609–620.
- Monticello, J., 2004. Editor’s edge. *GLAO News* 40, p. 4.

- O'Brien, K., 2001. Editorial: Is evidence-based orthodontics a pipedream? *Journal of Orthodontics* 28, p. 313.
- Paquette, D.E., Beattie, J.R. & Johnston, L.E., Jr., 1992. A long-term comparison of non-extraction and bicuspid-extraction edgewise therapy in "borderline" Class II patients. *American Journal of Orthodontics and Dentofacial Orthopedics* 102, pp. 1–14.
- Shaw, B., 2000. How relevant is the evidence-based process to orthodontics. *Evidence-based Dentistry* 2, pp. 7–8.
- Zuccati, G., Clauser, C. & Giorgetti, R., 2009. Randomized clinical trials in orthodontics: reality, dream, or nightmare. *American Journal of Orthodontics and Dentofacial Orthopedics*, 136, 634–637.

Reflections on a Decade of Evidence-Based Dentistry

David L. Turpin, DDS, MSD

Moore/Riedel Professor of Orthodontics, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA

The need to communicate current research findings of the highest level more effectively is becoming imperative in influencing clinical practice in the 21st century. In 1998 a research paper published in *Lancet* set off a firestorm of reactions whose damaging effects are still being felt today. The paper suggested a link between a greater risk of autism and the combined measles, mumps, and rubella vaccine routinely given to children. Finally, some parents had an answer to the mystery of why their children were afflicted by the disorder. However, we now know it wasn't the *right* answer (Wakefield et al. 1998).

Lancet has now retracted the 1998 paper, saying the lead author had been dishonest, violated research rules, and had subjected the 12 children involved with his study to needless suffering and procedures such as lumbar punctures and colonoscopies (Murch 2004). Dr. Andrew Wakefield recommended that the combined vaccine be split into three separate shots. But he didn't disclose that a year earlier he had patented a measles vaccine that could be used if the combined vaccine were discredited. Nor did he disclose that his research was partly funded by lawyers of parents seeking to sue vaccine makers.

Despite the retraction by *Lancet*, much damage has been done—and cannot be undone. Now, even though study after study has found no link between vaccination and autism, many parents are still more willing to believe the one, small, now-discredited study that supposedly did find an associated risk. Parents continue to give credence to the discredited *Lancet* study, and because of this, children's lives are endangered. Early and more effective communication with the public at large was needed in this case in support of childhood immunization.

With the publication of this text, I find it satisfying to realize how rapidly change in this area has been occurring. Several years ago (2003), while working on an editorial, I typed “evidence-based dentistry” into the PubMed database and got back nothing, a big zero, “no items found” (Turpin 2003). In 2010 the same question was answered with “2287 items found.” Fortunately, a number of people in dentistry are true believers in evidence-based research, and for this I am thankful. With early encouragement from Michael G. Newman, editor of the *Journal of Evidence-Based Dental Practice*, Mosby, Inc. sponsored the First International Conference on Evidence-Based Dentistry in Atlanta in 2003. This conference allowed those with experience in this new methodology to describe how to implement an evidence-based decision-making approach in everyday practice. This conference has become a landmark meeting that deserves credit for bringing together a wide range of sponsors, partners, researchers, educators, attorneys, and clinicians. The goals of the conference were as follows:

- Provide a venue for an accomplished group of international speakers to discuss a broad range of topics associated with the methods and outcomes of evidence-based initiatives and programs.
- Provide a context for, and examples of, cutting-edge evidence-based methodologies, skills, and research.
- Critically examine barriers and resistance to the evidence-based paradigm.
- Begin the process of culture change in education and clinical practice.
- Enhance networking and formation of new alliances and partnerships among attendees.

Since that time, the American Dental Association has been a strong proponent of multidisciplinary efforts to improve product assessment methods and advocates for the proper evaluation and use of the best available evidence in clinical practice. Following its lead in 2005, the American Association of Orthodontics adopted an official definition of evidence-based dentistry for the clinical practice of orthodontics.

Evidence-based dentistry (EBD) is an approach to oral health care that requires the judicious integration of systematic assessments of clinically relevant scientific evidence, relating to the patient’s oral and medical condition and history, with the dentist’s clinical expertise and the patient’s treatment needs and preferences. (AAO House 2005 Resolutions)

This process integrates the best research evidence, clinical expertise, and the patient’s treatment needs—three critical components in evidence-based practice. You can determine the best treatment and have the ability to complete it, but without patient acceptance, it doesn’t matter. The situation is different when a patient agrees to have a procedure, but the evidence does not support it. If the procedure is new or the research is incomplete, use of the best evidence might not be an option. What if several systematic reviews state that the procedure is unacceptable for correcting the problem and better alternatives are available? According to the rules of evidence-based practice, you should tell the patient. Mindful of this potential dilemma, the AAO House of Delegates charged the AAO and its Council on Scientific Affairs (COSA) to identify systematic reviews and meta-analyses on various orthodontic topics. Summaries of the findings provide a wealth of information for the practicing orthodontist.

The next time you examine an adult patient who asks what can be done to “cure” snoring and problems related to obstructive sleep apnea, you may want to know more about this subject. Take a look at the Cochrane Collaboration review of the topic.

Sleep apnea is characterized by recurrent episodes of partial or complete upper airway obstruction during sleep, leading to a variety of symptoms including excessive daytime sleepiness. The current first choice therapy is continuous positive airway pressure that keeps the upper airway patent during sleep. However, this treatment can be difficult for patients to tolerate and comply with on a long-term basis. Oral appliances have been proposed as an alternative to continuous positive pressure therapy. They keep the upper airway open by advancing the lower jaw forward or keeping the mouth open during sleep. This review found insufficient evidence to recommend oral appliances as first choice therapy for sleep apnea. When an active oral appliance was compared with an inactive oral appliance, there were improvements in daytime sleepiness and apnea/hypopnea severity. However, oral appliances proved less successful than continuous positive pressure in decreasing sleep disordered breathing. When an oral appliance was effective in treating sleep apnea, it was preferred to continuous positive pressure by some patients. Oral appliances may be more effective than corrective upper airway surgery. (Lim et al. 2004)

Another Cochrane systematic review questions the effectiveness of penicillin to guard against bacterial endocarditis before an invasive dental procedure.

There is no evidence about whether penicillin prophylaxis is effective or ineffective against bacterial endocarditis in people at risk who are about to undergo an invasive dental procedure. There is a lack of evidence to support published guidelines in this area. It is not clear whether the potential harms and costs of penicillin administration outweigh any beneficial effect. Ethically, practitioners need to discuss the potential benefits and harms of antibiotic prophylaxis with their patients and their cardiologists before a decision is made about administration (Oliver, Roberts & Hooper 2004).

But as technology continues to advance, the number of treatment options available can overwhelm the public, as well as many in the professional community. It is no surprise when patients become frustrated with the decision-making process. Who should deliver their care? At what age should it be started? Will braces be required, or can removable aligners do the job? Can orthodontic treatment be accomplished without jaw surgery? As a specialty, it is time to ask these questions. Do we know how to predictably prevent, manage, and treat malocclusions, with all their manifestations, efficiently and with the best possible outcomes? If the answer is yes, based on the best available evidence, is it not appropriate to write guidelines for the management and correction of malocclusions? Realistically, ours might be the only specialty in dentistry that has not already produced true practice guidelines for the standard of care. The American Academy of Periodontology has been writing guidelines for years and recently began developing new guidelines for managing patients with periodontitis (<http://www.perio.org>; Greenwall 2001). These guidelines are directed at defining levels of care appropriate for the general dentist. A more urgent need in our specialty might be the development of guidelines for the treatment of malocclusions by orthodontic specialists. In periodontology, it is the academy's hope that the latest guidelines will help improve the periodontal health of all patients with periodontitis. Evidence suggests that more patients would benefit from periodontal specialty care. Can we as a specialty learn from their experience?

Improving the quality of care with practice guidelines might mean challenging the beliefs that each patient is unique and that doctors must bring an individualized approach or plan of treatment to each patient. According to physician Dr Loren H. Roth (Gleckman & Carey 2006), quoted in a recent *Business Week* article, most illnesses and injuries can best be treated by standardized care. This idea horrifies most clinicians.

The vast differences in the way temporomandibular discrepancies (TMDs) are diagnosed and treated is a case in point. Some orthodontists claim that with fixed appliances they can make the occlusion perfect and solve TMD problems. The evidence now shows that some procedures are invasive and irreversible and might be inappropriate at best. Yet many dentists still believe that occlusion is the primary cause of TMD. It is no surprise that the world of TMD and orofacial pain is rife with differences of opinion based on “viewpoint” articles and case reports but not on the evidence.

Some in the profession are concerned about the misuse of guidelines by insurance companies. Although this is not a new threat, insurance companies have given the public the impression that they define the parameters of care by their regulations and coverage, even though their decisions might be contrary to evidence from well-designed, peer-reviewed studies and patient preferences. In evidence-based dentistry, there is a “conscientious, explicit and judicious use of the current best evidence” to be used in clinical decision making. This information is an adjunct, not a substitute, for clinical judgment and patient preference. When used in concert, it can provide optimal treatment. Back to our original premise: are we as a specialty ready to begin the long process of writing guidelines for the management and correction of malocclusions? Orthodontic guidelines can be found now on various websites, but few of these guidelines were written or endorsed by the American Association of Orthodontists (American Academy of Pediatric Dentistry Clinical Affairs Committee 2006)!

As the issue of who is best qualified to deliver specialty care continues to percolate throughout society, it becomes more critical than ever before to specify which procedures lead to the best treatment outcomes. Although most academics knowledgeable about evidence-based practice believe that we might never have high-level evidence for more than 50% of the procedures we currently use, we must strive to make use of what is well known by the research community. For instance, we know a great deal about the stability of orthodontic treatment, and this information is becoming more available to our members as well as the public. Take a minute to look at The Cochrane Library, and you’ll find a location titled, “Resources for journalists and bloggers” (Lentini-Oliveira et al. 2009). What do you think you will learn about the stability of open bite closure as a result of early treatment? It might be time for our specialty to define which treatment leads to the greatest stability when closing open bites or aligning mandibular teeth and make this available to our members in the form of practice guidelines.

For another source of high-level articles, look to the American Association of Orthodontists’ website for a meta-analysis of mandibular intercanine width in treatment and postretention: <http://www.aaomembers.org/library>. The best article on this topic was published in the *Angle Orthodontist* in 1997 and reviews 26 research studies that describe mandibular intercanine width changes in the long term (Burke et al. 1997). The combined sample comprised 1233 subjects divided into subgroups based on pretreatment classification, including extraction and nonextraction treatment. This study clearly supports the concept of maintaining the original intercanine width in orthodontic treatment when treatment stability is the desired outcome. Is it not time to make this available to our members

as a practice guideline? Once a Cochrane critical review or a meta-analysis based on randomized controlled trials or weighted articles is completed, it takes many opposing studies to reverse the findings. If agreement between all persons involved, including carefully invited expertise, can be reached in fulfilling the goal of developing usable practice guidelines, patient care would improve—and that's what it's all about.

Some orthodontists fear that guidelines will simply lead to greater medical and legal entanglements than in the past. This issue is raised when our specialty is challenged by federal and state governments to care for unmet dental needs of the population. Based on our specialty's ethics, our primary responsibility is to deliver the best care available to those in need, and legal liabilities will not necessarily increase with that effort. Another concern is the valid question of who will determine the standards. I think that this question is currently being dealt with in some creative ways by the medical profession. A commentary by Sniderman and Furberg (2009) entitled, "Why guideline-making requires reform," is germane to this concern. They suggest that the manner in which most guidelines are written needs to be reformed. A failure to change the process risks replacing one authority-based system with another, whereas the core objective should be to strengthen an evidence-based approach to improve clinical care. Their suggested approach calls for the inclusion of special expertise relevant to the guideline being written: that is, if it covers the types of radiographs required to diagnose and plan treatment for an impacted canine, an oral and maxillofacial radiologist should be on a subgroup of the committee. Then, when the total guideline committee agrees with the new or revised guideline, it should be posted on the Internet with an invitation to all interested clinical and didactic persons to comment. This openness helps to ensure that, when legitimate differences of scientific opinion exist, there is an opportunity for exchange before the committee confirms its decision on a guideline. Just to be safe, before publication of the new guidelines Sniderman and Furberg recommend that the journal editor should submit the guidelines for scientific review, just as is any other article. The editor could also publish alternate points of view if they are submitted after this public airing. Finally, all financial conflicts of interest with commercial entities should be acknowledged and disclosed in detail.

Surely the public is best assured of quality treatment by the application of a single high level of care—irrespective of the educational and experiential qualifications of the practitioners providing the services. ... There should be but one standard of practice for reviewing and assessing all orthodontic treatment. Practical standards of treatment must be established (Riolo & Vaden 2009a, 2009b).

It is when issues like this one find their way into the mainstream of discussion that I find reason to be involved in finding a broader understanding of evidence-based practice. The many publics we find ourselves being exposed to recently want exposure to new research findings in their quest to resolve clinical questions. It is clear that orthodontic leaders want their articles published in journals with high-impact factors and suitable to share knowledge. Greater use of the multisite research collaborations may be capable of providing a boost to orthodontic knowledge base. After viewing nearly 1000 manuscripts a year as editor-in-chief of the *American Journal of Orthodontics and Dentofacial Orthopedics*, it is clear to me the publication of more systematic reviews will not satisfy the demand for evidence. Orthodontists' thirst for knowledge must be applicable to solving

their patients' needs, and I believe that multicenter randomized controlled clinical trials will do that more quickly than any other type of research.

References

- American Academy of Pediatric Dentistry Clinical Affairs Committee, 2005–2006. Guidelines on management of the developing dentition and occlusion in pediatric dentistry. *Pediatric Dentistry* 27 (Suppl.), pp. 143–155.
- American Association of Orthodontics (AAO) House 2005 Resolutions; 16-05 EBDTF, 27-05 COSA, and 28-05 COSA. St. Louis, MO: American Association of Orthodontics.
- Burke, S.P., Silveira, A.M., Goldsmith, L.J. et al., 1997. A meta-analysis of mandibular intercanine width in treatment and postretention. *The Angle Orthodontist* 68, pp. 53–60.
- Gleckman, H., Carey, J., 2006. Medicine's industrial revolution. *Business Week* [online], May 29, 2006. Available at: http://www.businessweek.com/magazine/content/06_22/b3986015.htm [Accessed on December 7, 2006.]
- Greenwell, H., Committee on Research, Science and Therapy. American Academy of Periodontology, 2001. Guidelines for periodontal therapy. *Journal of Periodontology* 72, pp. 1624–1628.
- Lentini-Oliveira, D.A., Carvalho, F.R., Ye, Q. et al., 2009. Orthodontic and orthopaedic treatment for anterior open bite. *Cochrane Database of Systematic Reviews*, issue 2, Art. No. CD005515, DOI 10.1002/14651858.CD005515.pub2.
- Lim, J., Lasserson, T.J., Fleetham, J. et al., 2004. Oral appliances for obstructive sleep apnea. *The Cochrane Database of Systematic Reviews*, issue 4, Art No. CD004435.
- Murch, S.H., Anthony, A., Casson, D.H. et al., 2004. Partial retraction. *Lancet* 6, 363, p. 750.
- Oliver, R., Roberts, G.J. & Hooper, L., 2004. Penicillins for the prophylaxis of bacterial endocarditis in dentistry. *The Cochrane Database of Systematic Reviews*, issue 2, Art. No. CD003813.
- Riolo, M. & Vaden, J.L., 2009a. Standard of care: why it is necessary. *American Journal of Orthodontics and Dentofacial Orthopedics* 136, pp. 494–496.
- Riolo, M., Vaden, J.L., 2009b. How can the specialty establish a standard of care? *American Journal of Orthodontics and Dentofacial Orthopedics* 136, pp. 497–500.
- Sniderman, A.D., Furberg, C.D., 2009. Why guideline-making requires reform. *Journal of the American Medical Association* 30, pp. 429–431 [Online]. Available at: <http://jama.ama-assn.org/cgi/content/full/301/4/429> [Accessed on December 1, 2010].
- Turpin, D.L., 2003. First International Conference on Evidence-based Dentistry. Editorial. *American Journal of Orthodontics and Dentofacial Orthopedics* 124, p. 233.
- Wakefield, A.J., Murch, S.H., Anthony, A. et al., 1998. Ileal-lymphoid-nodular hyperplasia, non-specific colitis, and pervasive developmental disorder in children. *Lancet* 351, pp. 637–641.

Index

Note: *Italicized pages indicate a photo/figure; tables are noted with a t.*

- A
- AAO House of Delegates, 302
- ABO. *See* American Board of Orthodontists
- ABO-OGS. *See* American Board of Orthodontics Objective Grading Index
- About The Cochrane Collaboration database, 288*t*
- Absence of evidence, evidence of absence *vs.*, 128
- AC, 205*t*
- Acta Odontologica Scandinavica*, 125
- Acupuncture, TMD treatment and, 120
- ADA. *See* American Dental Association
- Adolescence
 - treatment of Class II malocclusion in, 54–56
 - functional appliance treatment, 54–56
 - headgear used in, 56–59
 - patient values, 56
- Adolescents
 - open bite and permanent dentition in, 103
 - open bite strategies for, 105
- Adults
 - Invisalign's appeal to, 177
 - open bite and permanent dentition in, 103–104
 - open bite strategies for, 105
- Advanced searches, in PubMed, 41
- Aesthetics, perceived benefits of orthodontic treatment and, 208
- Aesthetics awareness, prevalence of, 274
- African Americans, open bite in, in two age ranges, 100*t*
- Age of patient
 - evidence-based practice in Class III malocclusion dependent on, 276
 - prevalence of open bite and, 100, 100*t*
 - relapse and changes related to, 183
 - root resorption, orthodontic treatment and, 73, 74*t*
 - TMD and, 121
- Airway
 - anterior open bite and, 100
 - open bites, late mixed dentition and problems with, 102
- Alcoholism, severe root resorption during orthodontic treatment and, 72
- Alignment, open bite therapy, retention phase and, 104–105
- Alignment and fit of teeth, 191
 - assessing, 199–200, 202–204
 - prerequisites for objective assessment, 200, 200*t*
- Alveolar bone density, OIIRR and, 72
- Alveolar bone loss, data on orthodontic treatment and, 93
- American Academy of Periodontology, 303
- American Association of Orthodontics, 90, 302
- American Association of Orthodontists, 304
- American Board of Orthodontics Objective Grading Index, 200, 201*t*, 203*t*, 205*t*
- American Board of Orthodontists, Objective Grading System, 173
- American children, Class III incidence among, 248
- American Dental Association, 302
 - practice parameters, 10
 - web site of, 12

- American Journal of Orthodontics and Dentofacial Orthopedics*, 50, 305
 number of CRTs and SSTs published annually in, 284
 percentage of CRTs in, 284t
- Analogy, Hill's viewpoints on causality and, 18t
- Anchorage devices (temporary), open bite treatment and, 104, 111–112
- Anchorage reinforcement, Class II treatment with headgear provided during adolescence, 59
- AND command, Boolean operator, 36, 36, 37, 40, 42, 43
- Angle, Edward Hartley, 56, 295
 Class III malocclusion, subdivision I according to, 247–248, 248
 debate on Class III treatment timing and, 267
 on difficulties with Class III malocclusions, 254
 etiology of Class III malocclusion according to, 251–252
 “line of occlusion” defined by, 294
 pretreatment occlusion of male 16 years, 1-month-old with mesiocclusion of molars and canines, fitting Class III, subdivision I description of, 261
- Angle Orthodontist*, 50, 304
- Anterior crossbite
 graphic representation of, 249
 with mobility and recession on mandibular left central incisor, 94
- Anterior open bite
 Class III malocclusion, in 20-year, 1-month-old with, 264
 clinical definition of, 97–98
 closure of, through counterclockwise rotation of mandible, advantages with, 221
 correction, stability of—assessment of evidence, 97–113
- Anteroposterior discrepancies, stability of orthognathic surgery and, 217
- Apical displacement, orthodontic inflammatory root resorption and, 78
- Apical root resorption
 background and etiology of, 64–67
 duration of orthodontic treatment and, 75
 self-ligating brackets and, 144
- Appliance systems, TMD and orthodontic treatment studies on, 129
- Appliance type, root resorption and, 79
- Applied force magnitude, root resorption, orthodontic treatment and, 78
- Arch alignment, efficiency of, 140–141, 143
- Arch dimensional changes, self-ligating appliances and, 143
- Archwire sequencing, OIIRR and, 80
- Asian populations, Class III incidence among, 248
- Aspiration of practitioner, optimal outcomes and, 283
- Asthma, root resorption and, 71, 74t
- Attractiveness, importance of, in life, 208
- Australia and New Zealand Clinical Trials Registry, 33
- Averageness, facial attractiveness and, 208
- B
- Banded Hyrax appliances, 237
- Barbagallo, L. J., 76t, 170t
- Bass appliance, untreated control group vs. effectiveness of, 55
- Beauty, importance of, in life, 208
- Begg technique
 root resorption and, 79
 TMD, orthodontic treatment studies and, 129
- Begg (wraparound) retainers, 184
- Belief, knowledge vs., 16
- Bias, 283
 factoring out of systematic reviews, 274–275
 limiting
 in Cochrane Oral Health Group review process, 288
 randomized clinical trials and, 25
 systematic reviews and, 12
 nonrandomized retrospective clinical trials and, 242
 research designs ordered by increasing likelihood of, 21t
- Bibliographic databases, building a search strategy and, 38
- Bicortical screws, long-term relapse for, 220
- Bilateral sagittal split mandibular setback osteotomy with rigid internal fixation, 225
- Bilateral sagittal split osteotomy
 with counterclockwise rotation, open bite, permanent dentition, 103
 open bite therapy and, 106–107
 with rigid internal fixation
 cephalometric study, 221
 counterclockwise rotation of mandible and, 222
 stability of orthognathic surgery and, 217, 219

- stability of surgical mandibular
 - advancements with, 222
- surgical correction of mandibular
 - retrognathia and, 219, 220
- Bimaxillary protrusion, pretreatment/
 - posttreatment radiographs of 12-year-old female with, 69
- Bioefficient therapy, root resorption and, 79
- Biofeedback, TMD treatment and, 120
- Biological gradient, Hill's viewpoints on
 - causality and, 18*t*
- Bionator, early orthodontic treatment for Class
 - II malocclusion and, 52
- Bionator/headgear combination, Class II
 - malocclusion in adolescence and, 55
- Biopsychosocial model for TMD, 120
- Bioresorbable bicortical screws, short- and
 - long-term relapse for, 220
- Bisphosphonates, root resorption and, 71, 74*t*
- Bite opening, Class III adult orthodontic
 - options and, 260
- Bonded Hyrax appliances, 237
- Bonded retainers, 188
 - indication for, 183–184
 - multistrand, 186
 - various designs for, 186
- Bonding in orthodontics, 135
- Bone-borne expansion appliance, 241
- Boolean operators, 36, 36–37, 37, 43
- Borderline conditions, alternative treatment
 - options and, 274, 275
- Bracket design, plaque retention, periodontal
 - health and, 145
- Bracket prescription, OIIRR and, 80
- Brackets and bands, adolescents and, 103
- British Journal of Orthodontics*, 50, 284
- British Library Direct Plus, 34, 43
- British National Health Service, 5, 27
- BSSO. *See* Bilateral sagittal split osteotomy
- “Burn-out” in children, long-term compliance
 - and, 269
- C
 - Camouflage, Class III patients study, 260
 - Cardiff cohort study, facial landmarks and, 194, 195, 197
 - Caries, fluoride and reduction in, 150
 - Caries Research*, percentage of RCTs in, 284*t*
 - Case-control studies, 21*t*
 - advantages and disadvantages with, 23–24
 - evidence-based practice and, 262
 - Casein phosphopeptide-amorphous calcium
 - phosphate
 - applying, 150
 - demineralization reduction with, 150
 - systematic reviews on, 164
 - Case reports, 21*t*, 262
 - Case series, evidence-based practice and, 262
 - Caucasians
 - Class III malocclusion in, 255
 - open bite in, two age ranges, 100*t*
 - Causality
 - in clinical research, 17
 - Hill's viewpoints on, 17–18, 18*t*
 - CBCT. *See* Cone beam computerized
 - tomography
 - CCA, 203*t*, 205*t*
 - CCTs. *See* Controlled clinical trials
 - CDSR. *See* Cochrane Database of Systematic
 - Reviews
 - Cellular cementum
 - partial repair with, in cervical third of root, 68
 - total repair of root surface with, but with altered root contour, 68
 - total repair of total surface with, and original root contour reestablished, 68
 - Cementoblasts, orthodontic pressure and
 - damage to, 65
 - Cementum, orthodontic forces acting on, 65
 - CENTRAL database. *See* Cochrane Central
 - Register of Controlled Clinical Trials
 - Centre for Reviews and Dissemination
 - (University of York), 32
 - Cephalometric analyses, facial landmarks and, 192
 - Cephalometric data, dental assessments
 - supplemented with, 200
 - Cerebral palsy, open bite and, 100
 - Cervical pull headgear
 - bionator and, Class II malocclusion and, 52
 - biteplane combination, Class II
 - malocclusion and, 52
 - Charles II (king of Spain), inherited
 - mandibular prognathism in, 253
 - Chewing gum, fluoride added to, 150
 - Chewing muscles, TMD and, 120–121
 - Chin caps/chin cups
 - Class III malocclusion and, 254, 255, 256–257
 - open bite, permanent dentition–adolescent
 - and, 103
 - TMD, orthodontic treatment studies and, 129
 - Chinese Biomedical Literature Database, 33, 43
 - Chinese Clinical Trial Register, 33
 - Circumferential apical root resorption, 65
 - Circumferential supracrestal fiberotomy, 188

- Class I malocclusion, pseudo-Class II malocclusion vs., 250
- Class II malocclusion
 - craniofacial morphology and, 248–250, 249
 - early orthodontic treatment for, 51–54, 53–54
 - ethical issues in Class II research, 51
 - general summary, 60
 - growth, issues associated with, 224
 - mandible moved forward, mandibular plane rotated counterclockwise, 223–225
 - mandible moved forward, mandibular plane maintained or rotated clockwise, 217–219
 - maxilla up and mandible forward, 223–224
 - obtaining research evidence for treating increased overjets in, 50–51
 - synthesis of evidence, 59–60
 - treatment during adolescence, 54–56
 - functional appliance treatment, 54–56
 - headgear use, 56–59
 - patient values, 56
 - treatment of, 49–60
- Class II molar relationship, toward Class I, RME and, 241
- Class III malocclusion
 - adult treatment, 260–262
 - combined orthodontics and orthognathic surgery, 261–262
 - lower-face aesthetics dictates maxillary surgery only, 262
 - orthodontic options, 260–261
 - patient complaint favors mandibular surgery, 262
 - Angle's classification, 247–251
 - diagnostic considerations, 251
 - general characteristics, 248–250
 - pseudo-Class III, 250–251
 - subdivision I, 247–248, 248
 - application to a specific malocclusion, 265, 267–269
 - choice of treatment, 268
 - clinical question, 265, 267
 - treatment progress, 268–269
 - available evidence, 267–269
 - growth events, 268
 - timing of treatment in growing patients: earlier vs. later intervention, 267
 - changes in superimposed cephalograms T1, T2, and T2 to T3, 258
 - early treatment, 254–259
 - approach to, 254–255
 - existing evidence, 255
 - overcorrection dilemma, 257–259
 - overtreatment is better for stability of results, 257
 - timing of, 255
 - treatment is better than no treatment, 257
 - treatment modality: palatal expansion may not be required and chin cap success is questionable, 255–257
 - etiology of, 251–253
 - evidence-based treatment of, 262, 264–265, 267–269
 - evidence on diagnosis and treatment, 247–277
 - evidence search in individual decision making, 262, 264–265
 - defining the evidence, 262, 264
 - PICO to treatment selection, 265
 - foundations and variations of treatment, 254–262
 - growth, issues associated with, 228
 - lateral cephalometric tracing of a boy 14 years, 10-months-old, 252
 - mandible back, 224–225
 - maxilla forward, 225–226
 - maxilla forward and mandible back, 226–228
 - maxilla fully embedded within prognathic mandible, 253
 - maxillary arch in normal transverse relation with mandibular arch in, 254
 - perspective on scope of evidence, 269–275
 - compliance, 269
 - component analysis, 272
 - minimizing side effects, 270–271
 - objective conditions for intervention and research, 270
 - overcorrection of maxillary protraction, maxillary incisor inclination and spacing within arch, 271–272
 - predictability of results, 272
 - treatment timing and duration, 269
 - pretreatment, male 16 years, 1-month-old, fitting Angle's description of Class III, subdivision I, 261
 - pretreatment and posttreatment profiles, cephalographs, and occlusal views of man 30 years, 7-months-old, 263
 - results of evidence-based treatment: between neglect and acceptance, 273–275
 - state of evidence regarding, summary, 276–277

- superimposition of cephalographs of
 - matched control subjects at
 - corresponding observation periods,
 - T1-T2 (14 months) and T2-T3 (6
 - years), 258
- TMD studies and evaluations of, 129
- treatment of, in 5-year-old boy with primary
 - dentition, using combination of palatal
 - expander and face mask, 256
- treatment with straight-pull headgear
 - inserted in tubes attached to maxillary
 - first molars, 250
- variation in position of sella relative to
 - nasion in, 252
- Cleft lip, 193
- Clinical decision making, current best
 - evidence and, 304
- Clinical problem, turning into answerable
 - question, 265
- Clinical research
 - causality in, 17
 - changing landscape for, 291
- Clinical research designs, 15–16
 - introduction to, 15–16
 - research quality issues, 19–21
 - duration, 21
 - measurement issues, 19–20
 - placebo, 20–21
 - population (study subjects), 20
 - statistical analysis and sample size, 20
- scientific method, 16–18
 - developing a hypothesis, 16–18
 - testing a hypothesis, 18–19
- systematic reviews and meta analysis, 26–28
- Clinical skills of practitioner, optimal
 - outcomes and, 283
- Clinical Trials.gov, 44
- Clinical trials information. *See also* Controlled
 - clinical trials; Randomized clinical
 - trials/ randomized controlled trials
- electronic searching for, 31–44
 - how to search: constructing a search
 - strategy, 34–43
 - summary, 43
 - useful resources, 43–44
 - where to search: choosing databases,
 - 32–34
- CMDs. *See* Craniomandibular disorders
- CMR. *See* Cochrane Methodology Register
- Cochrane, Archibald, 5, 7, 12, 27
 - early years of, 6
 - evidence-based approach and influences on,
 - 6–7
 - legacy of, 7–9
- Cochrane Central Register of Controlled
 - Clinical Trials (CENTRAL), 32, 33,
 - 288, 288t
- Cochrane Collaboration, 27, 28, 31, 32, 51,
 - 110
 - aim and primary function of, 286
 - Cochrane Oral Health Group and, 10
 - enamel demineralization research and, 156
 - influence of, 8–9
 - logo, 8, 8
 - search filter for finding randomized
 - controlled trials in MEDLINE, 41
 - sleep apnea review, 303
 - web site, 33
- Cochrane Database of Systematic Reviews,
 - 32, 287, 288, 288t
- Cochrane Handbook of Systematic Reviews of*
 - Interventions, The*, 41, 44, 110, 124
- Cochrane Journal Club, web site for, 288
- Cochrane Library, The, 32–33, 43, 44, 286
 - accessing, 33
 - controlled vocabulary used in, 35
 - databases included in, 288t
 - proximity operators and, 38
 - resources for journalists and bloggers, 304
- Cochrane Methodology Register, 288t
- Cochrane Oral Health Group, 9, 10, 31, 44
 - editorial process of, 287, 287t
 - evidence-based care and, 286–288
 - statistical guidelines, TMD and orthodontic
 - treatment study, 125
- Cochrane Oral Health Group Trials Register,
 - TMD and orthodontics database
 - search, 124
- Cochrane Review*, 52
- Cochrane Review Groups, 33
- Cochrane reviews, relevant to orthodontics,
 - 289–290, 289t–290t
- Cochrane trials registers, accessing, 33
- “Cofounder summarization” method
 - (Miettinen), 297
- Coherence, Hill’s viewpoints on causality and,
 - 18t
- COHG. *See* Cochrane Oral Health Group
- Cohort studies, 21t
 - evidence-based practice and, 262
 - strengths and weaknesses of, 24
- Collective action, for improving evidence base
 - for orthodontics, 290–291
- Comparison groups, research quality issues
 - and, 20
- Completion rate, for functional appliances in
 - treating Class II malocclusion in
 - adolescence, 56

- Compliance
 central tendencies confounded by level of, 273–274
 orthopedic schemes and, 276
 sustained, as crucial for success of growth modification, 269
- Component analysis, imaging tools and, 272
- Composite for bonding orthodontic attachments, glass ionomer cement vs., 161–162
- Compound open bite, 101
- Computerized microradiography, demineralization and, 152
- Condition, completed search strategy for, 40
- Condylar positioning devices, surgical stability and, 228
- Condylar repositioning, 218
- Condyle morphology, open bite and, 100
- Cone beam computerized tomography, 192
- Conference proceedings, trials information and, 34
- Confidentiality approval, research governance and, 291
- Conflicts of interest, disclosure of, 305
- Consistency, Hill's viewpoints on causality and, 18*t*
- Consolidated Standards of Reporting Trials*, 24
- Consolidated Standards of Reporting Trials (CONSORT) Statement, 156
- CONSORT checklist
 quality reporting of RCTs and, 286
 trial reporting and adherence to, 291
- CONSORT Group, 131
- CONSORT guidelines, 145
- Continuous force application, discontinuous force application vs., 78–79
- Control groups, research quality issues and, 20
- Controlled clinical trials, 11. *See also* Clinical trials information; Randomized clinical trials/randomized controlled trials
 Cochrane Oral Health Group and, 288
 on expansion to correct posterior crossbite, 237
 number of, published annually on oral health topics, 285
 in orthodontic literature, 284, 284
- Controlled vocabulary
 constructing search strategy and, 35
 variance in, from database to database, 43
- Conventional ligation mode systems, reported time savings with self-ligation vs., 141*t*
- Copolymer screws, biodegradable, rigid fixation achieved with, 219
- Cortical bone, root proximity to, OIIRR and, 72
- Corticotomy, open bite, permanent dentition–adult and, 104
- Corticotomy/TADs combination, anterior open bite treatment and, 112
- COSA. *See* Council on Scientific Affairs
- Cost-effectiveness, 192
 activity data for five orthodontic practitioners, 206
 attributed costs to activity data for five orthodontic practitioners, 206*t*
 of orthodontic care, 204, 206–208
 pretreatment and posttreatment ICON scores: 40 and 84 cases for orthodontists A and B, 207
- Council on Scientific Affairs, 302
- Counterclockwise rotation, Class II open bites, 221–223
 restrospective studies, 221–222
 summary, 223
- CPP-ACP. *See* Casein phosphopeptide–amorphous calcium phosphate
- Craniomandibular disorders, 119
- Crib therapy
 open bite, permanent dentition–adolescent and, 103
 open bite treatment and, 102, 103
 six nonsurgical studies on, 106
- Crossover design, demineralization study and, 151–152
- Cross-sectional studies, 21*t*
 strengths and weaknesses of, 22–23
- Crowding and protrusion, pretreatment radiograph of 22-year-old female with, 64
- Crown/root ratio, unfavorable, orthodontic treatment and, 79
- D
- DAI. *See* Dental Aesthetic Index
- Damon SL brackets, retrospective clinical research on, 139–140
- Damon 3 appliance
 apical root resorption and, 144
 conventional appliance vs., RCT on, 141
- Damon 2 brackets, twin brackets vs., 141
- Damon II appliances, torque expression with MicroArch appliances and, 143
- DARE. *See* Database of Abstracts and Reviews

- Data acquisition, research quality issues and, 20
- Database of Abstracts and Reviews, 32, 288*t*
- Databases
 - in Cochrane Library, 288*t*
 - where to search in, 32–34
 - choosing the right platform, 34
 - Cochrane Library, 32–33
 - EMBASE, 32
 - gray literature, dissertations, and conference proceedings, 34
 - MEDLINE, 32
 - non-English language literature, 33
 - trials registers, 33
- Database searching, Boolean operators in, 36, 36–37, 37
- Data collection and analysis
 - on TMD and orthodontic treatment, 125–126
 - data extraction, 126
 - data synthesis, 126
 - study selection, 125
- Data safety and monitoring board, 25
- Deciduous dentition, prevalence of posterior crossbite in, 234–235
- Deep resorption, 65
- Delaire mask, in adults, SARPE and, 260–261
- Demineralization
 - plaque accumulation and, 149
 - updated Cochrane Review and, 158–160
- Demineralization during orthodontic treatment
 - background, 149–150
 - calculation of risk ratio, placebo varnish, *vs.* fluoride varnish, 160*t*
 - calculation of risk ratio (data derived from Luther et al.), 163*t*
 - casein phosphopeptide-amorphous calcium phosphate, 164
 - details of search strategies, updated
 - Cochrane review, 158–160 (box 10.2)
 - effectiveness of fluoride, in reducing enamel demineralization, 156–157, 160–164
 - EMBASE via Ovid search strategy, 160
 - flowchart for all potential articles identified following searches of electronic databases, 157
 - fluoride-releasing glass bead placed on orthodontic archwire, 163
 - limitations of previous research
 - clinical trials—random or alternate allocation, 151
 - inappropriate statistical analyses, 153
 - incidence *vs.* prevalence, 153
 - laboratory studies, 150–151
 - lack of sufficient power, 153, 155
 - masking of patients and clinicians, 152–153
 - parallel, split-mouth, or crossover design, 151–152
 - relevant outcomes, 152
 - reporting of trials, 156
 - short term or long term?, 151
 - methods of applying fluoride/CPP-ACP, 150
 - number of patients with at least one new demineralized lesion in experimental quadrant, 161*t*
 - prevention of, with fluoride-containing materials or casein phosphopeptide-amorphous calcium phosphate, 149–164
 - reducing enamel’s susceptibility to, 150
 - relative risk for dichotomous outcome:
 - parallel and split-mouth studies, 154–155 (box 10.1)
 - risk ratio and 95% confidence intervals
 - conventional GIC and conventional composite quadrants, 162
 - fluoride mouth rinse *vs.* fluoride-containing glass beads, 163
 - fluoride varnish *vs.* nonfluoride placebo varnish, 161
 - summary, 164
- Demineralized white lesions
 - new, in conventional GIC and conventional composite quadrants, 162*t*
 - new, in fluoride-containing glass beads *vs.* fluoride mouth rinse patients, 163*t*
 - patients with at least one, in experimental quadrant, 161*t*
 - risk ratio and 95% confidence intervals for outcome number of, fluoride varnish *vs.* nonfluoride placebo varnish, 161*t*
- Dental Aesthetic Index, 91, 203, 203*t*, 205*t*
- Dental aesthetics, perceived benefits of orthodontic treatment and, 208
- Dental attractiveness, 192, 209
- Dental caries, fluoride and reduction in, 150
- Dental casts, orthodontic treatment outcome and, 200
- Dental health, orthodontic treatment and, 208
- Dental open bites, skeletal open bites *vs.*, 98–99
- “Dental Practice Parameters for Oral Health,” 10
- DHC, 205*t*

- DI, 205†
- Digit habits
open bites and, 99
primary or early mixed dentition, 102
- Discontinuous force application, continuous force application *vs.*, 78–79
- “Dished-in” profile, “orthodontic look” and, 274
- Dissertations, trials information and, 34
- Distalization of molars, intraoral appliance and, in Class II treatment with headgear provided during adolescence, 59
- Distraction osteogenesis, 217, 219, 220
- DO. *See* Distraction osteogenesis
- Double-jaw surgery, correction of skeletal Class III malocclusion and, 227
- Downward bow, evaluating in studies of Class II treatment with headgear, during adolescence, 57, 58
- Drug-related resorption, 71
- Drug therapy, TMD and, 120
- DSMB. *See* Data safety and monitoring board
- Duration
of orthodontic treatment, root resorption and, 75
research quality issues and, 21
- Dynamax appliance, completion rate and, 56
- E
- Early adolescence phase (phase II), early orthodontic treatment for Class II malocclusion and, 51
- Early mixed dentition (phase I), early orthodontic treatment for Class II malocclusion and, 51
- Early orthodontic treatment
for Class II malocclusion, 51–54
stability of treatment, 53–54
- Earnings, physical attractiveness and, 208
- EARR. *See* External apical root resorption
- EBD. *See* Evidence-based dentistry
- EBO. *See* Evidence-based orthodontics
- EBP. *See* Evidence-based practice
- EBSCO, 34, 38
- Edgewise appliance, introduction of, 135
- Edgewise systems, root resorption and, 79
- Editorial process, Cochrane Oral Health Group, 287, 287–288
- Educational development, orthodontic treatment and, 208
- Effectiveness, randomized clinical trials and, 26
- Effectiveness and Efficiency* (Cochrane), 5
- Efficacy, randomized clinical trials and, 26
- Elastics, open bite therapy, retention phase and, 104
- Electronic records, constructing search strategy and, 34
- Electronic searches
on malocclusion and periodontal health, 91–92
on orthodontic treatment and periodontal health, 92
- Electronic searching for clinical trials information, 31–44
constructing search strategy, 34–43
Boolean operators, 36–37
building a search strategy, 38–41
controlled vocabulary, 35
electronic records, 34
free-text searching, 35–36
proximity operators, 38
search filters, 41–42
translating the strategy, 43
truncation and wildcards, 37–38
- introduction, 31
- where to search: choosing databases, 32–34
choosing right platform, 34
Cochrane Library, 32–33
EMBASE, 32
gray literature, dissertations, and conference proceedings, 34
MEDLINE, 32
non-English language literature, 33
trials registers, 33
- Electronic Theses Online Service, 34, 44
- EMBASE, 31, 32, 33, 43, 44
controlled vocabulary used in, 35
- Invisalign search, 168
- EMBASE.com, 34
- Enamel bonding techniques, discovery of, 135
- Enamel demineralization
fluoride and
fluoride-releasing glass beads *vs.* fluoride mouth rinse, 162–164
fluoride varnish *vs.* nonfluoride varnish, 156–157, 160
glass ionomer cement *vs.* composite for bonding orthodontic attachments, 161–162
plaque accumulation and, 149
reducing, effectiveness of products for, 156–157, 160–164
reducing susceptibility of, 150
- Endodontic treatment, root resorption and, 72–73, 74†

- Environmental factors, Class III malocclusion and, 251
- Epistemology, defined, 16
- Equipoise, 25
- Essix style retainers, open bite therapy, retention phase and, 104, 105
- Ethical issues, in Class II research, 51
- Ethics, research governance and, 291
- ETHOS. *See* Electronic Theses Online Service
- Eurocran Distraction Study, 241–242
- European Journal of Orthodontics*, 50, 284
- Evidence-based approach
- future of, in orthodontics, 13
 - influence of, 9
 - pioneering of, 5
- Evidence-based care in context, 283–291
- Cochrane Oral Health Group, 286–288
 - Cochrane reviews relevant to orthodontics, 289–290, 289*t*–290*t*
 - collective action to improve evidence base for orthodontics, 290–291
 - collective professional effort, 283
 - trials in orthodontic literature, 284–286
- Evidence-based clinical practice, defined, 12
- Evidence-based dentistry, 10–11
- American Association of Orthodontics' definition of, 302
 - application of, to orthodontics, 9–10
 - reflections on decade of, 301–306
- Evidence-based medicine
- Archie Cochrane and development of, 6–7
 - early years, 6
 - influences on, 6–7
- Evidence-based orthodontics, limitations of decision process in, 293–298
- Evidence-based practice
- in Class III malocclusion, as age-dependent, 276
 - decision making and, 262
 - PICO process and, 264–265, 265*t*
 - range of viewpoints on, clinician judgment and, 277
 - turning clinical problem into answerable question and, 265
- Evidence-based treatment, reality of: between neglect and acceptance, 273–275
- Evidence ladder, disavowing a priori rejection or blind adherence to, 274–275
- Evidence of absence, absence of evidence vs., 128
- Excerpta Medica Database. *See* EMBASE
- Experiment, Hill's viewpoints on causality and, 18*t*
- Experimental research designs, 22, 24–26
- quasi-experiments, 26
 - randomized controlled trials, 24–26
- Experimental trials, 21*t*
- Expert opinion, evidence-based practice and, 262
- External apical root resorption, 67
- active, terminating after appliance removal, 80
 - asthma and, 71
 - background and etiology of, 64–67
 - genetic predisposition to, 71
 - magnitude of overjet reduction during orthodontic treatment and, 73
- External root resorption, assessment of evidence, 63–81
- Extractions, nonsurgical studies on open bite therapy and, 106
- Extraction therapy, open bite, permanent dentition–adolescent and, 103
- Extrusion of molars, of Class II treatment with headgear provided during adolescence and, 58
- F
- Face, planes of, 193
- Face masks
- in adults, surgically assisted rapid palatal expansion and, 260–261
 - Class III malocclusion treatment and, 257
 - early, 254
 - in 5-year-old boy with primary dentition, combination palatal expander and, 256
- Face masks against miniplates, forward movement of maxilla, Class III treatment and, 271
- Face sizes, in sample of 20 male children, 196
- Facial attractiveness, 192, 208–209
- Facial changes, component analysis, angular/linear measurements and, 272, 273
- Facial data, dental assessments and, 200
- Facial extremes, aligning, 196–197
- Facial landmarks
- benefits with scaling, 196
 - categories of, 192
 - identifying, to assess change, 193
 - 3-D imaging and evaluating change in, 193
 - variation in
 - for cohort of 23 girls and 26 males, aged 12 and 16 years of age, 195
 - for 350 fifteen-year-old boys and girls, yellow and green ellipsoids representing scaled and unscaled, 193–194, 194

- Facial morphology, 191, 192–198
 changes in face as result of Le Fort I
 osteotomy moving maxilla forward
 5 mm, color map of, 198
 facial attractiveness and, 208
 similar growth patterns for similar
 morphologies for four males at ages 12
 and 16, 198
 superimposition of six faces on standardized
 framework for ages of 12 and 17,
 facial variation and forward projection
 of face shown, 197
 wide variations in, 196
 Facial pain, craniomandibular disorders and,
 119
 Facial structures, radiographic capturing of,
 192
 Falsifiability, 19
 FDA. *See* Food and Drug Administration
 Females
 dental attractiveness and, 209
 facial landmark analysis for, 194
 cohort aged 12 and 16 years of age, 195
 TMD and, 121
 Fibonacci series, facial attractiveness and, 208
 Field tags, 40, 43
 First International Conference on Evidence-
 Based Dentistry (2003), goals of, 302
 Fixed appliances, removable appliances *vs.*,
 79
 Fixed functional appliances, patient values for
 Twin Block *vs.*, in Class II treatment
 with headgear provided during
 adolescence, 60
 Fixed retainers, 183
 best type of, 186
 vacuum-formed retainers *vs.*, 186–187
 Fluoride
 dental caries reduced with, 150
 topical, methods of applying, 150
 Fluoride creams, 150
 Fluoride gels, 150
 Fluoride intervention, calculation of relative
 risk for dichotomous outcome,
 presence/absence of new demineralized
 lesions in parallel mouth studies and
 split-mouth studies, 154–155
 Fluoride lozenges, 150
 Fluoride mousse, 150
 Fluoride mouth rinse, 150, 162–164, 163*t*
 Fluoride-releasing glass beads
 fluoride mouth rinse *vs.*, in reducing enamel
 demineralization, 162–164, 163*t*
 placement of, on orthodontic archwire, 163
 Fluoride varnish, 150
 caries-preventive effectiveness of, 156–157,
 160
 nonfluoride varnish *vs.*, 156–157, 160
 placebo varnish *vs.*, new demineralized
 lesions and, 160*t*
 Fluor Protector, 157
 Food and Drug Administration, 25
 Force application, method of
 root resorption and
 continuous *vs.* discontinuous, 78–79
 treatment technique, 79
 type of appliance, 79
 Frankel appliances
 for Class II malocclusion, 52
 TMD treatment and, 128
 Frankfort horizontal, perpendicular lines to,
 98
 Free text, 43
 Free-text searching, 35–36
 Frequently Asked Questions pages, 43
 Frictional resistance
 to orthodontic tooth movement, 138–139
 in vitro studies, bracket type and ligation
 mode relative to, 139*t*
 Functional appliances. *See also* Fixed
 functional appliances
 open bite, permanent dentition–adolescent
 and, 103
 open bite therapy and, six nonsurgical
 studies, 106
 TMD, orthodontic treatment studies and,
 129
 Functional appliance treatment of Class II
 malocclusion
 maximum *vs.* incremental advancement of
 functional appliances, 55–56
 treatment carried out in one phase in
 adolescence with, 54–55
 Functional crossbite, 250
 G
 Gender
 dental attractiveness and, 209
 landmark positioning and, 192
 physical attractiveness, earnings and, 208
 root resorption, orthodontic treatment and,
 73, 74*t*
 TMD and, 120, 121
 Generalized Procrustes superimposition, 192
 Genetic influences
 anterior open bite and, 100
 on OIIRR, 70–71
 Genioplasty, relapse and, 222

- Genomewide association studies, facial morphology and, 193
- German Clinical Trials Registry, 33
- Gingival factors, relapse related to, 182
- Gingival recession, orthodontic treatment and, 93
- Gingivitis, studies on interaction between malocclusion and, 91–92
- Glacow's law, 28
- Glass ionomer cement, composite for bonding orthodontic attachments *vs.*, 161–162
- Glossotomy, 99, 103–104
- Golden proportion, facial attractiveness and, 208
- Gray literature, trials information and, 34
- Great Lakes Association of Orthodontists Newsletter*, 295
- Growing patients, Class III and timing of treatment in, 267
- Growth
- Class II malocclusion and, 224
 - Class III malocclusion and, 228
 - forecasting, Class III treatment and, 257–259
 - modification, open bite, permanent dentition in adolescent and, 103
 - open bite and, 104
 - PICO process, Class III in 12-year, 3-months-old boy and, 268
 - relapse and, 183
- Guideline making, medical and legal concerns around, 305
- Gum, fluoride added to, 150
- H
- Haas appliances, 237
- Handicapped Labio-Lingual Deviation Index, 203, 203*t*
- Hand searching, TMD, orthodontics database search and, 125
- Harvold appliance, Class II malocclusion and, 52
- Hawley retainers, 184, 188
- anterior and occlusal views of, 184
 - effectiveness of, 185
 - full-time *vs.* part-time basis with, 185
- Hawthorne effect, randomized clinical trials and, 296
- Headgear
- open bite therapy and, six nonsurgical studies on, 106
 - successful forward movement of maxilla, Class III treatment and, 270
 - treatment of Class II malocclusion with, during adolescence, 56–59
- Health-care information, dealing with unmanageable amounts of, 5, 27
- Health management organization, 204
- Health-related quality of life measures, 209
- Health Technology Assessment Database, 288*t*
- Heat exercises, TMD and, 120
- Help pages, of electronic databases, 43
- Herbst appliance
- completion rate and, 56
 - patient perceptions about, 56
 - in treatment of Class II malocclusion in adolescence, 55
- High-pull headgear, open bite, permanent dentition–adolescent and, 103
- Hits, search filters and cutting on down number of, 41–42
- HLD. *See* Handicapped Labio-Lingual Deviation Index
- HMAR, 205*t*
- HMO. *See* Health management organization
- Holes in retainers, open bite therapy, retention phase and, 104
- Horizontal plane, of face, 193
- Hormone deficiency, root resorption and, 71
- HRQoL measures. *See* Health-related quality of life measures
- HTA. *See* Health Technology Assessment Database
- Human Genome Project, 9
- Human trials without controls, 21*t*
- Hyphens, search strategy and problems with, 40
- Hypodivergent facial patterns, stability of orthognathic surgery and, 219
- Hypopituitarism, root resorption and, 71
- Hypothesis
- developing, 16–18
 - establishing, 21
 - operationalizing, 19
 - testing, 18–19
- Hypothyroidism, root resorption and, 71
- I
- ICC. *See* Intraclass correlation coefficient
- ICON (Index of Complexity, Outcome and Need), 200, 201*t*, 202, 202*t*, 204, 205*t*
- cohort and cross-sectional studies
 - percent of cases in, by complexity category, 173
 - Invisalign data collection, 169
- IL-1B* gene, OIIR linked to, 71, 74*t*
- Imaging tools, component analysis and, 272

- Implanted zygomatic and mandibular plates, with Class 3 elastics, successful forward movement of maxilla, Class III treatment and, 270–271
 - Incisal inclinations, normalizing, overcorrection through maxillary protraction and, 271–272
 - Incisor overjet, Class II malocclusion and, 52, 51
 - Incisor retroclination, Angle's observation on, 248
 - Index of Orthodontic Treatment Need, 203, 200, 203*t*, 205*t*
 - Indian Clinical Trials Registry, 33
 - Institute of Medicine Report, on future of dental education, 10–11
 - Insurance companies, guidelines misuse and, 304
 - International Federation of Pharmaceutical Manufacturers and Associations, 33
 - International Trials Registry Platform, 44
 - Interproximal reduction, relapse reduction and, 187, 187*t*, 188
 - InterTASC group, 41
 - InterTASC Search Filters Resource, 44
 - Intervention, adding terms to search strategy, 40
 - Intraclass correlation coefficient, 202
 - Intraoral appliance, evaluating in studies of Class II treatment with headgear provided during adolescence, 59
 - Intraoral vertical ramus osteotomy, 227
 - Intruded teeth, varying severity of root resorption in, 66
 - Intrusive tooth movements, root resorption, orthodontic treatment and, 78
 - Inverted-L osteotomy, 111, 218
 - Invisalign search (Cochrane), 168
 - Invisalign therapy
 - adult patient and appeal of, 177
 - characteristics of each case published as case report or in a case series, 174*t*–175*t*
 - cohort and cross-sectional studies, 171*t*–172*t*
 - conclusions, 178
 - discussion, 176–178
 - introduction, 167–168
 - methods
 - data collection, 169
 - searches, 168–169
 - search summary, 168
 - percent of cases in table 11.3 by complexity category, 173
 - results, 169, 173, 176
 - systematic reviews
 - of lower quality evidence, 167–178
 - randomized controlled trials and, 170*t*
 - IOA. *See* Intraoral appliance
 - IOTN. *See* Index of Orthodontic Treatment Need
 - Iranian Registry of Clinical Trials, 33
 - Ivoclar Vivadent, 157
 - IVRO. *See* Intraoral vertical ramus osteotomy
- J**
- Jasper Jumper removable plate system, Class II treatment with headgear provided during adolescence, 58
 - Jensen retainers, 184
 - “Jiggling” forces, root resorption and, 79
 - Journal of American Dental Association*, 125
 - Journal of Clinical Periodontology*, 284*t*
 - Journal of Craniomandibular Practice*, 125
 - Journal of Evidence-Based Dental Practice*, 302
 - Journal of Oral and Maxillofacial Surgery*, 125
 - Journal of Oral Rehabilitation*, 125
 - Journal of Periodontology*, 284*t*
- K**
- Kappa statistic, 202
 - Keywords, free-text searching and, 35
 - Kloehn bow cervical pull headgear, landmark study on, 57
 - Knowledge, belief vs., 16
 - KoreaMED, 33, 44
- L**
- Lancet*, autism and vaccination research paper, 303
 - Landmark positioning, facial morphology and, 192
 - Late mixed dentition, open bite treatment options for, 102–103
 - Lateral skull cephalometric radiographs, detecting root resorption and, 69
 - Latin American and Caribbean Health Sciences Literature Resource, 33, 44
 - League tables, for cost-effectiveness of orthodontic care, 207
 - LeFort I maxillary advancement, stability of, vs. with maxillary palatal expansion with protraction face mask, 226
 - LeFort I maxillary impaction with clockwise rotation, open bite, permanent dentition–adult and, 103

- LeFort I osteotomy
 - advancing maxilla, sagittal split ramus osteotomy and, 227
 - maxilla moved forward 5 mm, color map showing changes in face as result of, 198
- LeFort I surgery, disadvantages with, 111
- LeFort osteotomies with posterior impaction, open bite therapy and, 106–107
- Light microscopes, root resorption detection with, 67
- Likert scales, 202
- LILACS. *See* Latin American and Caribbean Health Sciences Literature Resource
- Lip habits, open bite and, 99
- Long-term relapse, contemporary approach to, 183
- Low back pain, TMD and, 120
- L-thyroxine, reduction of root resorption and, 71
- M
- Macroglossia, glossotomies for patients with, 99
- Macrognathic mandibles, Class III malocclusions with, treatment, 258–259
- Magnetic resonance imaging, 192, 193
- Magnitude of applied force, root resorption, orthodontic treatment and, 78
- Male facial landmarks, for cohort aged 12 and 16 years of age, 195
- Males
 - dental attractiveness and, 209
 - different face sizes in sample of children, 196
 - facial landmark analysis for, 194
 - facial morphologies identified from Cardiff cohort study, 197
 - physical attractiveness, earnings and, 208
 - similar growth patterns for similar facial morphologies for, at ages 12 and 16, 198
- Malocclusion, 294. *See* Class I malocclusion; Class II malocclusion; Class III malocclusion; Maxillary expansion; Transverse maxillary expansion
 - anterior open bites, as most challenging type of, 97
 - description of, 89–90
 - evidence on relationship between periodontal health and, 91–92
 - prevalence of, 90
 - root resorption and severity and type of, 73
 - studies on interaction between gingivitis and, 91–92
 - three examples of open bite, 98
- Malocclusion indices, periodontal health and, 91
- Mandible back, Class III malocclusion
 - retrospective studies, 224–225
 - reviews, 225
 - summary, 225
- Mandible forward
 - with mandibular plane maintained or rotated clockwise, Class II malocclusion
 - prospective studies, 219
 - retrospective studies, 218–219
 - with mandibular plane rotated counterclockwise, Class II malocclusion
 - retrospective studies, 221–222
 - summary, 223
- Mandibular advancement, stability of orthognathic surgery and, 218–219
- Mandibular clockwise rotation, orthopedic schemes and, 276
- Mandibular counterclockwise rotation and advancement genioplasty, pretreatment, presurgery, and posttreatment cephs/photos of adult open bite patient treated with, 112
- Mandibular displacement, 250
- Mandibular first molars, apical root resorption and, 67
- Mandibular forward growth, Class III, overcorrection dilemma and, 258
- Mandibular functional shift, eliminating, transverse maxillary expansion and, 233
- Mandibular growth, Class II vs. Class III malocclusion and, 257–258
- Mandibular headgear, Class III treatment and, 257
- Mandibular incisors, apical root resorption and, 67
- Mandibular left central incisor, anterior crossbite with mobility and recession on, 94
- Mandibular prognathism
 - Class III malocclusion, in 20-year, 1-month-old with, 264
 - Class III malocclusion associated with, 251
 - inherited, in Charles II of Spain, 253
 - not as prevailing component of mesiocclusion, 276

- Mandibular retrognathia
 - BSSO and DO, for surgical correction of, 219, 220
 - Class II malocclusion and, 217
 - correction of, 218
- Mandibular surgery
 - Class III malocclusion, patient complaint and, 262
 - open bite therapy and, 106–107
 - open bite treatment and, primary argument against, 111
- Manual positioning technique, condylar positioning devices vs., 228
- Masking of patients and clinicians, studying demineralization and, 152–153
- Maxilla, growth of, 257
- Maxilla forward
 - Class III malocclusion
 - retrospective studies, 225–226
 - summary, 226
 - Class III treatment and, 270, 271
 - mandible back and: Class III malocclusion
 - retrospective studies, 226–227
 - summary, 228
- Maxillary advancement and mandibular setback using rigid fixation, simultaneous, 3-D stability of, 226–227
- Maxillary constriction, etiology of, 234
- Maxillary expansion
 - face mask, overcorrection and, 257–258
 - future directions, 241–243
 - nonrandomized retrospective clinical trials, 242
 - questions for future research, 242–243
 - randomized clinical trials, 242
 - interventions, outcomes and evidence, 236–238, 240–241
 - to correct posterior crossbite, 237–238
 - effects of RME and SARME on nasal airway dimensions, 240
 - effects of SARME using bone-borne expansion appliance, 241
 - immediate and long-term stability of SARME, 240–241
 - long-term effects of, on arch perimeter, 240
 - rapid, immediate effects of, 237
 - rapid, long-term skeletal effects of, 238
 - rapid, long-term stability of, 238, 240
 - slow, immediate effects of, 237
 - spontaneous improvement of Class I molar relationship toward Class I with RME, 241
 - systematic reviews on, 236
 - long-term stability: summary of systematic reviews, 239*t*
 - overcorrected overjet, female 10 years, 9-months-old treated with protraction face mask and, 259
- Maxillary fixed appliances, spontaneous reduction of recession and mobility of mandibular left central incisor after correction of crossbite with, 94
- Maxillary incisor proclination, overcorrection of overjet and, 275
- Maxillary incisors
 - apical root resorption and, 67
 - panoramic radiographs of 12-year-old female with bimaxillary protrusion who experienced moderate root resorption of, during orthodontic treatment, 69
 - root resorption and proximity of, to cortical plate, 72
- Maxillary molars, EARR, asthma and, 71
- Maxillary palatal expansion with protraction face mask, stability of LeFort I maxillary advancement vs., 226
- Maxillary premolars, orthodontically induced root resorption in, 68
- Maxillary protraction
 - limitations with, 276
 - orthopedic schemes and, 276
 - overcorrection through, normalizing incisal inclinations and, 271–272
- Maxillary retrognathism
 - Class III malocclusion, in 20-year, 1-month-old with, 264
 - prevalence of, 249
- Maxillary surgery
 - lower-face aesthetics dictating choice of, 262
 - open bite therapy and, surgical studies on, 106–107
 - open bite treatment and, 111
- Maxilla up
 - mandible forward and: Class II malocclusion
 - retrospective studies, 223
 - summary, 224
- Measurement, research quality issues and, 19–20
- MEAW. *See* Multiloop edgewise technique
- Mechanotherapy, 274
- Medical Subject Headings in MEDLINE. *See* MeSH terms

- MEDLINE, 28, 31, 32, 33, 43, 124
 controlled vocabulary used in, 35
 Invisalign search, 168
 search filter for finding randomized
 controlled trials in, 41
 strategy, translating, 43
 via PubMed, 44
 wildcard in, 37
- Megapulse, TMD and, 120
- Mental retardation, open bite and, 100
- MeSH Browser (NLM), 39, 44
- MeSH terms
 exploded and unexploded searches with, 35
 identifying, building a search strategy and, 39
 PubMed search strategy example, 40
- MeSH tree, for orthodontic appliances, 35*t*
- Mesiocclusion, 247
 in adult, sparse research on, 276
 correction at early age, later
 development during facial
 development and, 276
 early correction of, 259
 environmental induction of, 249–250
 forecasting growth and, 257–259
 mandibular prognathism not as prevailing
 component of, 276
- Meta-analysis, 8, 12, 21*t*, 26–28
 caricaturing, 273
 evidence-based practice and, 262
- Metal retainers, 186
- Meta-Register of Controlled Clinical Trials, 33
- MicroArch appliances, torque expression with
 Damon II appliances and, 143
- Micro-CT, 67
- Microhardness testing, demineralization and, 152
- Midpalatal implant, evaluating in studies of
 Class II treatment with headgear
 provided during adolescence, 59
- Miettinen, O. J., method of “confounder
 summarization,” 297
- Milk, fluoride added to, 150
- Miniplates, long-term relapse for, 220
- Miniscrews or miniplates, for temporary
 anchorage devices, open bite treatment,
 111–112
- Minne expansion springs, slow maxillary
 expansion and, 237
- Minor resorption, 67
- “Misalignment” of facial features, reducing
 effect of, 196–197
- Mixed dentition patients
 nine months of crib therapy in, 103
 prevalence of posterior crossbite in,
 234–235
- Moderate resorption, 67
- Molar distalization, evaluating in studies of
 Class II treatment with headgear
 provided during adolescence, 58–59
- Mouth breathing, anterior open bite and, 100
- Mouth problems, open bite, late mixed
 dentition and, 102
- Mouth rinses, fluoride, 150
- MRI. *See* Magnetic resonance imaging
- Multiloop edgewise technique
 open bite, permanent dentition–adolescent
 and, 103
 open bite therapy and, six nonsurgical
 studies on, 106
- Multistrand bonded retainer, 186
- Myofunctional therapy, open bite treatment
 and, 102
- N
- NAB at end of phase II, final, effect of early
 treatment on: functional vs. control,
 53*t*
- Nasal airway dimensions, effects of RME and
 SARME on, 240
- Nasal obstruction, Class III malocclusion and,
 251
- Nasal width, lateral, rapid maxillary expansion
 and, 238
- Nasion-menton, as reference line with open
 bite, 98
- National Health and Nutrition Examination
 Survey, 90
- National Institute for Health Research (UK),
 290
- National Institutes of Health (US), 25, 33, 290
- National Library of Medicine, 35
 MeSH Browser, 44
- Neglect of evidence, illustrating, 273
- Netherlands Clinical Trials Register, 33
- Neurological/neuromuscular deficits, anterior
 open bite and, 100
- Neutral zone, 182
- Newcastle-Ottawa Quality Assessment Scale,
 92
- NHANES III, 100
- NHS Economic Evaluation Database, 288*t*
- NLM. *See* National Library of Medicine
- Non-English language literature, 33
- Nonfluoride varnish, fluoride varnish vs.,
 156–157, 160

- Nonrandomized retrospective clinical trials,
bias and, 242
- NOT command, Boolean operator, 36, 37, 43
- NOTI, 200, 201*t*
- O
- OA. *See* Occlusal adjustment
- Objective measures, for evaluating treatment
need and outcome, 200
- Observational research designs
case-control studies, 23–24
cohort studies, 24
cross-sectional studies, 22–23
- Occlusal adjustment, TMD and, 120
- Occlusal equilibration
open bite, permanent dentition–adult and,
104
open bite treatment and, 112
- Occlusal factors
relapse related to, 182
TMJ disorders and, 119
- Occlusal forces and contacts, evaluating in
studies of Class II treatment with
headgear provided during adolescence,
58
- Occlusal indices, 200
aim of, 208
comparison of seven indices, 202*t*–203*t*,
204
correlation coefficients for, 205*t*
developing, for specific purposes, 202
examples of, type of assessment and
validity, 201*t*
- Occlusal plane, as reference line with open
bite, 98
- Occlusion Feature Index, 91
- OI, 205*t*
- OIIIR. *See* Orthodontically induced
inflammatory root resorption
- One Man's Medicine* (Cochrane), 5
- Open bite, 97–113
background and etiology of, 97–100
in Caucasians and African Americans, in
two age ranges, 100*t*
classification by age category, 101*t*
conclusions about, from two systematic
reviews, 110–111
distribution of subjects with, 101*t*
evidence on long-term stability for
correction of, 105–108, 110
future directions for treatment of, 111–112
gaps in knowledge about, 111
nine months of crib use in mixed dentition
patient, 103
pretreatment, posttreatment, and 2 years
posttreatment, 110
pretreatment, presurgery, and posttreatment
cephs/photos of adult patient treated
with mandibular counterclockwise
rotation and advancement genioplasty,
112
prevalence of, 100–102
spontaneous correction of, 101
strategies for adolescents and adults, 105
summary remarks, 112–113
tendency and open bite, 99
three examples of, 98
treatment options for, 102–105
impact of severity and growth status, 104
late mixed dentition, 102–103
permanent dentition–adolescent, 103
permanent dentition–adult, 103–104
primary or early mixed dentition, 102
retention, 104–105
- Open bite closure through counterclockwise
rotation of mandible and intermaxillary
wire fixation, discontinuation of, 221
- Open bite deformities
correction with mandible moved forward
with mandibular plane rotated
counterclockwise
retrospective studies, 221–222
summary, 223
- Open bites, closing, glossotomies for patients
with macroglossia and, 99
- Open System for Information on Grey
Literature in Europe, 44
- Operationalization, testing a hypothesis and,
19
- Optimal outcomes, practitioner's aspiration,
clinical skill, treatment choice and, 283
- Oral habits, open bite and, 99
- Oral Health Review Group Journal Hand-
searchers Manual*, 125
- Oral health topics, number of RCTs and CCTs
published annually on, 285
- Oral Surgery, Oral Medicine, and Oral
Pathology*, 284*t*
- OR command, Boolean operator, 36, 37, 37,
43
- Orthodontically induced inflammatory root
resorption, 63
active, termination of, after appliance
removal, 81
adequacy of 2-D radiographs to analyze
root resorption, 67, 69–70
age of patient and, 73
classification of, 67

- genetic predisposition to, 71, 74*t*
- major methodological criteria and results
 - from included RCTs in systematic review, 76*t*–77*t*
- prevalence and detection of, 67–70
- prevention and treatment options for, 79–80
- risk factors for, 74*t*
- three types of, 65
- Orthodontically induced root resorption, in
 - maxillary premolars, varying degrees of repair in, 68
- Orthodontic appliances
 - example of MeSH tree for, 35*t*
 - open bite therapy and, six nonsurgical studies on, 106
- Orthodontic forces, root resorption following
 - termination of, 66–67
- Orthodontic literature, trials in, 284–286
- “Orthodontic look,” “dished-in” profile and, 274
- Orthodontic practice, making rational
 - decisions in, 11–12
- Orthodontic research, long-term and
 - multivariable nature of, upper-level studies and, 276–277
- Orthodontics. *See also* Temporomandibular
 - joint disorders and orthodontics
 - application of evidence-based dentistry to, 9–10
 - Cochrane reviews relevant to, 289–290
 - summary of, completed or in progress, 289*t*–290*t*
 - collective action to improve evidence base for, 290–291
 - contemporary, conflict within, 293
 - future of evidence-based approach in, 13
- Orthodontics/orthognathic surgery
 - combination for Class III, 261–262
 - lower-face aesthetics dictates maxillary surgery only, 262, 263
 - patient complaint favors mandibular surgery, 262, 264
- Orthodontic space closure, rate of, in split
 - mouth design, 143
- Orthodontic tooth movement, research on
 - frictional resistance to, self-ligation and, 138–139
- Orthodontic treatment. *See also*
 - Demineralization during orthodontic treatment; Maxillary expansion; Retention; Root resorption and orthodontic treatment; Transverse maxillary expansion
 - cost-effectiveness of, 204, 206–208
 - evidence on relationship between
 - periodontal health and, 92–93
 - future directions on studying long-term effects of periodontal health and, 93–94
 - open bite, impact of severity, growth status and, 104
 - perceived benefits of
 - dental attractiveness, 209
 - facial attractiveness, 208–209
 - patient satisfaction, 210
 - sociopsychological factors, 209–210
 - periodontal health and, 90
 - PICO process, Class III in 12-year, 3-months-old boy and, 268
 - prevalence of, 90
 - variation of practitioners in recommending treatment, and determining
 - acceptability of outcome of, 199, 199
- Orthodontic trials, goodness of outcome and, 296
- Orthodontists
 - activity data for five orthodontists, 206
 - attributed costs to activity data for five orthodontists, 206*t*
 - cost-effectiveness and individual variations
 - in practices of, 208
 - guiding principles and values of, 211
 - pretreatment and posttreatment ICON
 - scores for 40 and 84 cases for, 207
 - relapse prevention and, 183
- Orthognathic surgery
 - assessment of outcome relative to facial
 - surface analyzed prior to and after, 197–198
 - severe skeletal dysplasias and, 276
- Orthognathic surgery: stability of, 217–229
- anteroposterior discrepancies, 217
- Class II malocclusion
 - growth, 224
 - mandible moved forward with
 - mandibular plane maintained or rotated clockwise, 217–219
 - mandible moved forward with
 - mandibular plane rotated counterclockwise, 221–223
 - maxilla up and mandible forward, 223–224
- Class III malocclusion
 - growth, 228
 - mandible back, 224–225
 - maxilla forward, 225–226
 - maxilla forward and mandible back, 226–228

- Orthognathic surgery: stability of, *Continued*
 randomized trials, 219–221
 summary on, 229
- Orthopedic rapid maxillary expansion, 235
- Osteoclastogenesis, OIIR and, 71
- Orthodontic forces, action and consequences of, 65
- Outcome, assessment of, 191–192
- Overcorrection, Class III treatment and dilemma of, 257–259
- Overjets
 early treatment on, end of phase 2:
 functional appliance vs. control, 53*t*
 obtaining research evidence for treating,
 Class II malocclusions, 50–51
 overcorrected, profile photographs,
 lateral cephalographs, and lateral
 occlusal views of female 10 years,
 9-months-old, treated with maxillary
 expansion and protraction face mask,
 259
 overcorrection of, allowing potential
 decompensation of maxillary incisor
 proclination, 275
- Ovid, 34, 38
- P
- Pacifier use, prolonged, anterior open bites and, 99
- Pain experience, self-ligating brackets and, 144
- Palatal expander, Class III malocclusion treatment, in 5-year-old boy with primary dentition, combination face mask and, 256
- Palatal expansion
 early treatment of Class III malocclusion and, 254
 indicated, but may not be required in Class III treatment, 255–256
- Palatal plane, mesiocclusion and, superior-posterior tip of, 249
- Panoramic radiographs, periapical radiographs vs., in analyzing root resorption, 67
- PAR. *See* Peer Assessment Rating
- Parallel design, demineralization study and, 151–152
- Parallel mouth studies, calculation of relative risk for dichotomous outcome, presence/absence of new demineralized lesions in split-mouth studies and, 154–155
- PAR index, 204
- Participants, building a search strategy and, 39
- PAs. *See* Periapical radiographs
- Passive appliances, early treatment of Class III malocclusion and, 254
- Patient intervention comparison outcome. *See* PICO process
- Patient satisfaction, 192
 orthodontic treatment and, 210
- Patient values
 completion rate, 56
 examples of, 56
 fixed functional appliances vs. Twin Block in Class II treatment with headgear provided during adolescence, 60
 patient perceptions, 56
- PDL. *See* Periodontal ligament
- Peer Assessment Rating, 200, 201*t*, 205*t*
- Peer Assessment Rating score
 effect of early treatment on, at end of phase II: functional vs. control, outcome 3
 PAR score, 53*t*
 stability of occlusions and, 53
- Peer review, Cochrane Oral Health Group, 287, 287, 288
- Penicillin prophylaxis, Cochrane systematic review on, 303
- Periapical radiographs, panoramic radiographs vs., in analyzing root resorption, 67
- Pericision, relapse reduction and, 188
- Periodontal disease
 evidence that malocclusion is cause of, 90
 prevalence of, 90
- Periodontal factors, relapse related to, 182
- Periodontal health
 evidence for relationship between malocclusion and, 91–92
 evidence for relationship between orthodontic treatment and, 92–93
 future directions on studying long-term effects of orthodontic treatment on, 93–94
 self-ligating brackets and, 145
- Periodontal ligament, orthodontic forces and ischemic necrosis of, 65
- Periodontal pocket depth, data on, 93
- Periodontitis, American Academy of Periodontology and new guidelines for treatment of, 303
- Permanent dentition
 open bite, adolescents and, 103
 open bite, adults and, 103–104
- Personal contact, TMD and orthodontics database search and, 125
- Personal opinion, 21*t*
- Pharmaceutical companies, registers of clinical trials maintained by, 33

- Physical attractiveness, importance of, in life, 208
- Physiotherapy, TMD and, 120
- PICO process
 applied to severe underbite in 12-year, 3-months-old boy, 265–269, 266, 267*t*
 available evidence, 267
 choice of treatment, 268
 clinical question, 265, 267
 growth events, 268
 treatment progress, 268–269
 description of, 264–265, 265*t*
- Piers Harris score, self-esteem measured with, 210
- Placebo, research quality issues and, 20–21
- Placebo varnish, fluoride varnish vs., number of patients with at least one new demineralized lesion, 160*t*
- Plaque accumulation, orthodontic appliances and, 121, 149
- Plaque retention, self-ligating brackets and, 145
- Plausibility, Hill's viewpoints on causality and, 18*t*
- Polarized light microscopy, studying demineralization and, 152
- Population, research quality issues and, 20
- Porter arch
 correcting anterior crossbite in primary dentition and, 256
 early treatment of Class III malocclusion and, 254
- Positional malrelationship, 250
- Positioners, 184
 minor corrections achieved with, 167
 open bite therapy, retention phase and, 104
- Posterior bite blocks, open bite therapy, retention phase and, 104
- Posterior crossbite
 causes of, 234
 expansion and correction of, 237–238
 incidence of, in various studies, 234*t*
 prevalence of, in deciduous and mixed dentition, 234–235
- Posture, open bite and, 99
- Preadjusted edgewise appliance, advent of, 135
- Precementum layers, orthodontic pressure and damage to, 65
- Prediction models, Class III, variables in, 272
- Prevalence studies, 22
- Primary or early mixed dentition, open bite treatment options for, 102
- Procrustes analyses, 192
- Prognathic mandibles, Class III malocclusions with, treatment for, 258–259
- ProQuest, 34
- Protocols
 in Cochrane Library, 288
 Cochrane Oral Health Group and, 287, 287, 288
- Protraction face mask, overcorrected overjet, female 10 years, 9-months-old treated with maxillary expansion and, 259
- Proximity operators, database searching and, 38
- Pseudo-Class III, 250–251
- Pseudo-open bite, 101
- Pterygoid dysjunction, SARME, bone-borne expansion appliance and, 241
- Published literature, problems with, 27
- PubMed, 34, 38, 43
 advanced search in, 41
 MEDLINE via, 44
 search strategy example, 40
- Q
- QLF. *See* Quantitative light-induced fluorescence
- QoL. *See* Quality of life
- Quad helix
 correcting anterior crossbite in primary dentition and, 256
 early treatment of Class III malocclusion and, 254
 expansion springs, slow maxillary expansion and, 237
- Quality of life, 208, 209
- Quality of outcome, 191–211
 alignment and fit of teeth, 199–200, 202–204
 conclusion, 211
 cost-effectiveness, 204, 206–208
 dental attractiveness, 209
 facial attractiveness, 208–209
 facial morphology, 192–199
 patient satisfaction, 210
 sociopsychological factors, 209–210
- Quantitative light-induced fluorescence, studying demineralization and, 152
- Quantitative 3-D volumetric evaluation, of root resorption craters, 69–70
- Quasi-experiments, 21*t*, 26
- Quasi-randomized studies, 125
- R
- Race
 dental attractiveness and, 209
 prevalence of open bite and, 100–101, 100*t*

- Radiographic markers, to help assess
 - distalization of molar teeth, in studies of Class II treatment with headgear during adolescence, 58
- Radiographs, root resorption detection with, 67
- Randomization, 25
- Randomized clinical trials/randomized controlled trials, 21, 22, 24–26
 - advantages and disadvantages with, 25
 - application of evidence-based dentistry to orthodontics and, 9
 - best practices for, 24
 - Cochrane and development of, 7
 - Cochrane Oral Health Group and, 10, 288
 - defined, 24–25
 - evidence-based practice and, 262
 - on expansion to correct posterior crossbite, 237
 - lack of, in orthodontics, 12
 - low external validity in, reasons for, 26
 - on maxillary expansion, 242
 - multicenter, orthodontists' search for knowledge and, 305–306
 - number of, published annually on oral health topics, 285
 - in orthodontic literature, 284, 284, 284*t*
 - orthodontics and shortcomings with, 296–298
 - purpose of, 295
 - search filter for finding, in MEDLINE, 41
 - on stability of orthognathic surgery, 219–221
 - on temporomandibular joint disorders and orthodontics, 123
- Rapid maxillary expansion
 - Class II molar relationship toward Class I, spontaneous improvement with, 241
 - effects of, on nasal airway dimensions, 240
 - Haas, and resurgence of, 236
 - immediate effects of, 237
 - long-term skeletal effects of, 238
 - long-term stability of, 238, 240
 - orthopedic, 235
- RCTs. *See* Randomized clinical trials/ randomized controlled trials
- Reference lines, open bite and, 98
- Reference lists, TMD and orthodontics
 - database search and, 124–125
- Refutation, 18
- Relapse
 - in bilateral sagittal split mandibular setback osteotomy with rigid internal fixation, 225
 - causes of, 182–183
 - growth, 183
 - occlusal factors, 182
 - periodontal and gingival factors, 182
 - soft tissue pressures, 182
 - conclusions, 188
 - defined, 182
 - long-term, contemporary approach to, 183
 - prevention of, orthodontist and, 183
 - reducing, adjunctive techniques for, 187–188
 - interproximal reduction, 187, 187
 - percision, 188
- Removable appliances, fixed appliances vs., root resorption and, 79
- Removable retainers, 183, 188
 - daily retention regimen for, 184–185
 - most effective type of, 185
 - original type of, 184
- Research designs
 - experimental, 22, 24–26
 - quasi-experiments, 26
 - randomized controlled trial, 24–26
 - observational, 22–24
 - case-control, 23–24
 - cohort, 24
 - cross-sectional, 22–23
 - order of, by increasing likelihood of bias, 21*t*
- Research governance, 291
- Research quality issues
 - duration, 21
 - measurement, 19–20
 - placebo, 20–21
 - population (study subjects), 20
 - statistical analysis and sample size, 20
- Resin-reinforced ribbon retainers, 186
- Resorption, drug-related, 71. *See also* Apical root resorption
- Retainers, 183–186
 - fixed, 186–187
 - removable, 184–185
 - types of, 183
 - vacuum-formed, 185, 185
- Retention, 181–188. *See also* Relapse; Retainers
 - importance of, 181
 - introduction, 181
- Retention phase, open bite therapy and, 104–105
- “Retention Procedures for Stabilizing Tooth Position After Treatment with Orthodontic Braces,” 181

- Reverse-L osteotomy, open bite therapy and, surgical studies on, 106–107
- Review team, Cochrane Oral Health Group, 287, 287
- Ribbon retainers, 186
- RME. *See* Rapid maxillary expansion
- Root proximity to cortical bone, OIIR and, 72
- Root resorption. *See also* Orthodontically induced inflammatory root resorption
 - active, in immediate posttreatment radiograph, 64
 - analyzing, adequacy of 2-D radiographs in, 67, 69–70
 - defined, 64
 - external apical, background and etiology of, 64–67
 - history of, orthodontic treatment and, 70
 - occurrence of, in orthodontically treated teeth, 67
 - undermined, in cervical third of root with no repair, 68
 - varying severity of, in intruded teeth, 66
- Root resorption and orthodontic treatment
 - evidence for, 70–75, 78–79
 - long-term prognosis for, 80
 - orthodontic treatment-related risk factors, 74–75, 78–79
 - amount of apical displacement, 78
 - direction of tooth movement, 78
 - magnitude of applied force, 78
 - method of force application, 78–79
 - treatment duration, 75
 - patient-related risk factors, 70–71
 - genetic influences, 70–71
 - history of root resorption, 70
 - tooth root morphology, 70
- QUOROM statement flow diagram
 - outlining systematic review of titles, abstracts, and full-text articles on, 75
- summary and future directions, 80–81
- systemic factors, 71–74
 - alveolar bone density, 72
 - asthma, 71
 - chronic alcoholism, 72
 - drug-related resorption, 71
 - endodontic treatment, 72–73
 - gender, 73
 - hormone deficiency, 71
 - patient age, 73
 - previous trauma, 72
 - root proximity to cortical bone, 72
 - severity and type of malocclusion, 73
- Root surface, in cervical third of root with normal dentin, acellular root cementum, and periodontal ligament, 68
- Royal London Hospital, 55
- RR. *See* Root resorption
- Russell Lock edgewise attachment, 135
- S
- Sagittal ramus osteotomies, retrospective studies on, 218
- Sagittal split osteotomy, open bite treatment and, 111
- Sagittal split ramus osteotomy, LeFort I osteotomy for advancing maxilla, 227
- Sample size, research quality issues and, 20
- SARME. *See* Surgically assisted rapid maxillary expansion
- SARPE. *See* Surgically assisted rapid palatal expansion
- Scaling, facial landmarks and benefits of, 196
- Scanning electron microscopes, root resorption detection with, 67
- Schuchart procedure, open bite, permanent dentition–adult and, 103
- Scientific method
 - hypothesis development, 16–18
 - naturalistic answers vs. metaphysical answers in, 17
 - testing hypothesis, 18–19
- Scope of evidence
 - Class III treatment success and compliance, 269
 - component analysis, 272
 - interaction between overcorrection of maxillary protraction, maxillary incisor inclination, and spacing within arch, 271–272
 - minimizing side effects, 270–271
 - objective conditions for intervention and research, 270
 - predictability of results, 272
 - treatment and duration, 269
- Search engines, 38
- Search filters, 41–42, 43
- Search question, identifying elements of, 39
- Search strategy
 - constructing, 34–43
 - Boolean operators, 36–37
 - controlled vocabulary, 35
 - electronic records, 34
 - free-text searching, 35–36

- Search strategy, constructing *Continued*
 proximity operators, 38
 search filters, 41–42
 truncation and wildcards, 37–38
 translating, 43
- Search syntax, electronic databases, 34
- Second World War, 6, 7
- Section headings, building a search strategy and, 38
- Self-esteem
 early orthodontic treatment for Class II malocclusion and, 51, 52, 59–60
 perceived benefits of orthodontic treatment and, 208
 Piers Harris score and, 210
- Self-ligating appliances, root resorption and, 79
- Self-ligating brackets
 defined, 135
 InOvation R, sequential derotation of UL3 with selective use of, 136
- Self-ligating edgewise systems, properties of conventional systems and, 136
- Self-ligation, 135–145
 both second premolars extracted, 137
 case following removal of orthodontic appliances, 138
 comparative studies of rate of initial orthodontic alignment with self-ligating brackets and conventional brackets, 142*t*
 conclusions, 145
 glass ionomer cement placed on first molars to disengage occlusion, 137
 history of self-ligating appliances, 135–136
 influence of self-ligating brackets on deleterious treatment effects
 apical root resorption, 141
 plaque retention and periodontal health, 145
 subjective pain experience, 141
 introduction, 135
 laboratory findings, 138–139
 light NiTi coil spring and elastomeric traction placed on initial aligning wire, 137
 NiTi archwire (0.016-inch) fully engaged, 137
 OIIRR and, 80
 presenting malocclusion with severe maxillary arch crowding and palatal displacement of maxillary lateral incisors, 137
 properties of conventional and self-ligating preadjusted edgewise systems, 136
 prospective research, 140–141, 143–145
 reported time savings with self-ligating over conventional systems, 141*t*
 retrospective clinical research, 139–140
 treatment outcomes and duration
 arch dimensional changes and torque expression, 143
 efficiency and ease of use, 140
 efficiency of arch alignment, 140–141, 143
 overall treatment duration, 143
 rate of space closure, 143
 upper arch spacing closed, 137
 in vitro studies on influence of bracket type and ligation mode on frictional resistance, 139*t*
- Sella, Class III malocclusion and variation in position of, relative to naision, 252
- Sensitive search strategy, 31, 43
- Severe resorption, defined, 67
- Severity of open bite, impact of, 104
- Short-wave diathermy laser treatment, TMD and, 120
- SilverPlatter, 34
- Simple descriptive studies, 21*t*
- Simple open bite, 101
- Single-jaw surgery, 221
- Skeletal change, evaluating in studies of Class II treatment with headgear provided during adolescence, 57, 60
- Skeletal dysplasias, severe, orthognathic surgery favored for, 276
- Skeletal open bites, dental open bites vs., 98–99
- Skeletal relationship, early orthodontic treatment for Class II malocclusion and, 51, 52
- Sleep apnea, 303
- Slow maxillary expansion, immediate effects of, 237
- SmartClip, intermolar expansion with, 143
- SmartClip brackets, efficiency of, 140–141, 143
- Social development, perceived benefits of orthodontic treatment and, 208
- Sociopsychological factors, 192
 orthodontic treatment and, 209–210
- Soft tissue changes, relapse and, 182, 188
- Space closure, rate of, in split mouth design, 143
- Spatial repair patterns, following termination of orthodontic forces, 66–67
- Specificity, Hill's viewpoints on causality and, 18*t*

- Speech and tongue therapy, open bite treatment and, 99
- Splint therapy, TMD and, 120
- Split-mouth design
demineralization study and, 151–152
glass ionomer cement vs. composite for bonding orthodontic attachments in white spot reduction, 161–162
- Split-mouth studies, calculation of relative risk for dichotomous outcome, presence/absence of new demineralized lesions in parallel mouth studies and, 154–155
- Spring aligners, 184
- Spurs, open bite therapy, retention phase and, 104
- Standard edgewise technique, root resorption and, 79
- Statistical analysis, research quality issues and, 20
- Straight-wire treatment technique, root resorption and, 79
- Strength of association, Hill's viewpoints on causality and, 18*t*
- Streptokinase, 9
- Study subjects, research quality issues and, 20
- Subject headings, 34
- Surface resorption, 65
- Surgery
Class III patients treated with, comparative study, 260
open bite, permanent dentition–adult and, 103
TMD and, 120
- Surgically assisted rapid maxillary expansion, 235–236
effects of, with bone-borne expansion appliance, 241
immediate effects and long-term stability of, 240–241
- Surgically assisted rapid palatal expansion, face mask in adults and, 260–261
- Surgical stability, improving, condylar positioning devices and, 228
- Symbols, for truncation and wildcards, 38
- Symmetry, facial attractiveness and, 208
- Synonyms, building a search strategy and, 38–39
- Systematic reviews, 12, 21*t*, 26–28
advantages with, 12
on casein phosphopeptide-amorphous calcium phosphate, 164
on Class II treatment findings, 51–52
on Class II treatment with headgear during adolescence, 57
on Class III malocclusion, factoring out bias in, 274–275
Cochrane collaboration and science/methodology of, 8
Cochrane Oral Health Group and, 10
evaluating horizontal relapse and bilateral sagittal split advancement osteotomy with rigid fixation, 220
evaluating long-term stability of maxillary expansion, 239*t*
evidence-based practice and, 262
features of, 27–28
high quality, Cochrane Collaboration and, 110
on long-term stability of open bite correction, 105–108, 110
conclusions from reviews, 110–111
inclusion and exclusion criteria for, 108, 111
long-term follow-up of nonsurgical studies, 109
long-term follow-up of surgical studies, 109
nonsurgical studies, 106
surgical studies, 106–107
three aims identified, 106
treatment success, stability, and long-term success–nonsurgical studies, 106*t*
treatment success, stability, and long-term success–surgical studies, 107*t*
on maxillary expansion, 236
NOT command and, cautionary note, 37
on relationship between orthodontic treatment and periodontal health, 92–93
searching electronic databases for, 31
on sleep apnea, 303
- T
- TADs. *See* Temporary anchorage devices
- Teeth, quality of outcome and alignment and fit of, 199–200, 202–204
- Temporality, Hill's viewpoints on causality and, 18*t*
- Temporary anchorage devices
biological growth characteristics, etiologic elements and, 276
open bite treatment and, 111–112
- Temporomandibular joint
defined, 119
healthy, Class II malocclusion: growth and, 224

- Temporomandibular joint disorders and
 - orthodontics, 119–131
 - conclusions, 131
 - controversy surrounding, 121–122
 - criteria for considering studies for review
 - types of interventions, 124
 - types of outcome measures, 124
 - types of participants, 123–124
 - types of studies, 123
 - data collection and analysis, study selection, 125–126
 - data extraction, 126
 - data synthesis, 126
 - description of studies
 - characteristics of interventions, 126–127
 - characteristics of outcome measures, 127
 - characteristics of participants, 126
 - characteristics of trial setting and investigators, 126
 - performance bias, 127
 - discussion about, 128–130
 - effects of interventions, 127–128
 - future research recommendations, 130
 - methods, 123–126
 - objectives, 122
 - results, 126–128
 - search methods for identification of studies
 - checking reference lists, 124–125
 - hand searching, 125
 - language, 124
 - personal contact, 125
 - unpublished studies, 125
- 3-D coordinate system, standardized, female and male facial landmarks for 12 and 16 years of age superimposed on, 195
- 3-D imaging capture techniques, 192, 211
- 3-D imaging techniques, facial morphology and radiographic outcome assessments complemented by, 198
- 3-D stability, of simultaneous maxillary advancement and mandibular setback using rigid fixation, 226–227
- Thrombolytic therapy, 9
- Thumb crib, 102
- Thumb guards, 102
- Thyroxine, reduction of root resorption and, 71
- Tissue engineering, 274
- Titanium bicortical screws, rigid fixation achieved with, 219
- Title registration, Cochrane Oral Health Group, 287, 287
- TMDs. *See* TMJ disorders
- TMJ. *See* Temporomandibular joint
- TMJ disorders, 294. *See also*
 - Temporomandibular joint disorders and orthodontics
 - causes of, 120
 - common signs and symptoms of, 120
 - defined, 119
 - diagnosis and treatment of, differences of opinion over, 304
 - distinct profile for patients affected by, 121
 - low back pain and, 120
 - prevalence of, 119–120
 - prognosis of, 122
 - psychogenic causes of, 120
 - treatment options for, 120
- TNFRSF11A*, EARR and, 71, 74†
- Tongue cribs, 102
 - open bite, permanent dentition–adolescent and, 103
- Tongue posture, open bites, late mixed dentition and, 102
- Tongue thrusting, open bite and, 99
- Tonsillectomy, open bite, late mixed dentition and, 102
- Tooth aligners, minor corrections achieved with, 167
- Tooth movement direction, root resorption, orthodontic treatment and, 78
- Toothpaste, fluoride in, 150
- Tooth root morphology, OIIRR and, 70
- Topical fluoride, methods of applying, 150
- Torque expression, self-ligating appliances and, 143
- Training Manual for Handsearchers*, 125
- Transverse dimension, orthodontic treatment of–assessment of the evidence, 233–243
- Transverse maxillary expansion
 - background, 234–236
 - etiology of maxillary constriction, 234
 - orthopedic rapid maxillary expansion, 235
 - prevalence of crossbite in deciduous and mixed dentition, 234–235, 234†
 - surgically assisted rapid maxillary expansion, 235–236
 - introduction of, 235
 - wide use of, 233
- Transverse occlusal correction, palatal expansion, important clinical observation about, 254–255
- Transverse plane, of face, 193
- Trauma, history of, root resorption during orthodontic treatment and, 72, 74†

- Treatment choice
 - PICO process, Class III in 12-year, 3-months-old boy and, 268
 - practitioner, optimal outcomes and, 283
- Treatment progress, PICO process, Class III in 12-year, 3-months-old boy and, 268–269
- Trials. *See also* Clinical trials information; Controlled clinical trials; Randomized clinical trials/randomized controlled trials
 - number of reports of, published 2000–2009, according to country in which they were performed, 285
 - in orthodontic literature, 284, 284, 284
 - topics, 2000–2009, 286
- Trials registers, 33
- Truncation, 37–38, 43
- Tweed technique, root resorption and, 79
- Twin Block appliance
 - completion rate and, 56
 - early orthodontic treatment for Class II malocclusion and use of (UK group), 52
 - investigating modification of, in treatment of Class II malocclusion in adolescence
 - patient perceptions about, 56
 - patient values for fixed functional appliances *vs.*, in Class II treatment with headgear provided during adolescence, 60
 - in treatment of Class II malocclusion in adolescence, 55
- 2-D radiographs, root resorption analysis and, 67, 68, 69, 69
- U
- UL3, sequential derotation of, with selective use of InOvation R self-ligating brackets, 136
- Ultrasound, TMD and, 120
- Underbite
 - severe, in 12-year, 3-months-old boy, 266
 - available evidence, 267
 - choice of treatment, 268
 - clinical question, 265, 267
 - growth events, 268
 - treatment progress, 268–269
- University departments, significant role of, in education and research, 291
- University of North Carolina Dentofacial Program, 218
- Unpublished studies, TMD, orthodontics database search and, 125
- Upward bow, evaluating in studies of Class II treatment with headgear provided during adolescence, 57, 58
- U.S. Health and Vital Statistics, 100
- V
- Vacuum-formed retainers, 185, 185, 188
 - effectiveness of, 185
 - fixed retainers *vs.*, 186–187
 - full-time *vs.* part-time basis with, 185
 - thermoplastic, 184
- Variables, in research designs, 21
- Vertical plane, of face, 193
- Victory, efficiency of SmartClip brackets *vs.*, 140–141
- Virtual Health Library, 33
- Visual analog scales, 202
- W
- Web of Knowledge, 44
- Web of Science, Invisalign search, 168
- Weight of evidence, testing a hypothesis and, 19
- White spot reduction, glass ionomer cement *vs.* composite for bonding orthodontic attachments, 161–162
- WHO. *See* World Health Organization
- Wildcards, 37–38, 43
- Wire osteosynthesis, relapse and, 222
- Wits appraisal, distinguishing camouflage treatment from surgical treatment, adult orthodontic options, Class III, 260
- Women, physical attractiveness, earnings and, 208
- World Health Organization, 33
- World Health Organization Gateway, 44
- Z
- ZETOC, 34, 44